Defense Nuclear Agency
Alexandria, VA 22310-3398

DNA-TR-94-125

Evaluation of PAT SAW 10c Portable Static Scales

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February 1996

Technical Report

CONTRACT No. DNA MIPR-93-625

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REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. AGENCY USE ONLY (Leave blank)

2. REPORT DATE
960201

3. REPORT TYPE AND DATES COVERED
Technical 910901 - 920930

4. TITLE AND SUBTITLE
Evaluation of PAT SAW 10c Portable Static Scales

5. FUNDING NUMBERS
C - DNA MIPR-93-625

6. AUTHOR(S)
Rosa L. Santoni

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
U.S. Army Corps of Engineers
Waterways Experiment Station
3909 Halls Ferry Road
Vicksburg, MS 39180-6199

8. PERFORMING ORGANIZATION REPORT NUMBER

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)
Defense Nuclear Agency
6801 Telegraph Road
Alexandria, VA 22310-3398
ACVT/Simelton

10. SPONSORING/MONITORING AGENCY REPORT NUMBER
DNA-TR-94-125

11. SUPPLEMENTARY NOTES

12a. DISTRIBUTION/AVAILABILITY STATEMENT

Approved for public release; distribution is unlimited.

12b. DISTRIBUTION CODE

13. ABSTRACT (*Maximum 200 words*)

U.S. Army Corps of Engineers Waterways Experiment Station conducted tests of weighing multiaxle vehicles using the PT SAW 10c portable static scales in both a loaded and half loaded condition on level and smooth surfaces. The tests were designed to determine the accuracy of the PAT scales. The equipment used during the test included four vehicles, two PAT SAW 10c scales, and wood leveling boards. The use of the Mississippi scales was necessary to determine the accuracy of the PAT scales. Each vehicle's axle was weighed 30 times. One special test was included to verify the axle height effect when the vehicles was weighed. The data was analyzed with frequency histograms, normal probability plots, and test of hypothesis.

14. SUBJECT TERMS
Accuracy
Normal Test
Confidence Interval
PAT Scale
Test of Hypothesis
Portable Static Scales

15. NUMBER OF PAGES
92

6. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT
UNCLASSIFIED

18. SECURITY CLASSIFICATION OF THIS PAGE
UNCLASSIFIED

19. SECURITY CLASSIFICATION OF ABSTRACT
UNCLASSIFIED

20. LIMITATION OF ABSTRACT
SAR

NSN 7540-280-5500

Standard Form 298 (Rev.2-89)
Prescribed by ANSI Sts. 239-18
298-102

CLASSIFIED BY:

N/A since Unclassified.

DECLASSIFY ON:

N/A since Unclassified.

SUMMARY

This report describes the results of the evaluation of PAT SAW 10 portable static scale. The field data was obtained weighing four representative vehicles on two scales, Mississippi scale (a part of a permanent weighing station), and PAT scale. The data was required to estimate the number of runs needed to obtain an accuracy of ±1 percent of the gross vehicle weight. The mean, standard deviation, variance, covariance, and confidence intervals were calculated for each sample. In addition, the ratio between the measured and true weight was obtained. The normability of the samples was verified by use of frequency histograms, and normal probability plot. As a result, an accuracy of 1 percent at a 95 percent confidence level can be obtained for the four test vehicles using the PAT scale. The accuracy can be obtained when the vehicles axles are at the same height. It was also found that the percents of error are greater for loaded vehicles than for the unloaded vehicles.

PREFACE

The work reported herein was sponsored by the Defense Nuclear Agency (DNA) and was conducted at the Waterways Experiment Station (WES). This effort was performed with the support of the Pavement System Division's (PSD) Weigh-In-Motion (WIM) research program to weigh multiaxles vehicles using portable low profile axle scales.

The study was conducted at the U.S. Army Engineer Waterways Experiment Station under the general supervision of Dr. William F. Marcuson III, Director, Geotechnical Laboratory (GL), and under the direct supervision of Dr. George M. Hammitt II, Chief, Pavement System Division, and Dr. Albert J. Bush III, Chief, Criteria Development and Applications Branch (CDBA). The analysis and report was prepared by Ms. Rosa L. Santoni.

The WIM research program was directed by Dr. A. J. Bush, Chief, Criteria Development and Applications Branch, Mr. R. M. Bradley was the Principal Investigator, and Ms. R. L. Santoni was the co-investigator.

Dr. Robert W. Whalin was Director of WES during the preparation of this report. COL Bruce K. Howard, EN, was Commander.

CONVERSION TABLE

Conversion factors for U.S. Customary to metric (SI) units of measurement.

MULTIPLY → / TO GET ←	BY → / BY ←	TO GET / DIVIDE
angstrom	1.000 000 x E -10	meters (m)
atmosphere (normal)	1.013 25 x E +2	kilo pascal (kPa)
bar	1.000 000 x E +2	kilo pascal (kPa)
barn	1.000 000 x E -28	meter^2 (m2)
British thermal unit (thermochemical)	1.054 350 x E +3	joule (J)
calorie (thermochemical)	4.184 000	joule (J)
cal (thermochemical/cm^2)	4.184 000 x E -2	mega joule/m^2(MJ/m^2)
curie	3.700 000 x E +1	* giga becquerel (GBq)
degree (angle)	1.745 329 x E -2	radian (rad)
degree Fahrenheit	t_k=(t°f+4.59.67)/1.8	degree kelvin (K)
electron volt	1.602 19 x E -19	joule (J)
erg	1.000 000 x E -7	joule (J)
erg/second	1.000 000 x E -7	watt (W)
foot	3.048 000 x E -1	meter (m)
foot-pound-force	1.355 818	joule (J)
gallon (U.S. liquid)	3.785 412 x E -3	meter^3 (m^3)
inch	2.540 000 x E -2	meter (m)
jerk	1.000 000 x E +9	joule (J)
joule/kilogram (J/kg) radiation dose absorbed	1.000 000	Gray (Gy)
kilotons	4.183	terajoules
kip (1000 lbf)	4.448 222 x E +3	newton (N)
kip/inch^2 (ksi)	6.894 757 x E +3	kilo pascal (kPa)
ktap	1.000 000 x E +2	newton-second/m^2 (N-s/m^2)
micron	1.000 000 x E -6	meter (m)
mil	2.540 000 x E -5	meter (m)
mile (international)	1.609 344 x E +3	meter (m)
ounce	2.834 952 x E -2	kilogram (kg)
pound-force (lbs avoirdupois)	4.448 222	newton (N)
pound-force inch	1.129 848 x E -1	newton-meter (N.m)
pound-force/inch	1.751 268 x E -2	newton/meter (N/m)
pound-force/foot^2	4.788 026 x E -2	kilo pascal (kPa)
pound-force/inch^2 (psi)	6.894 757	kilo pascal (kPa)
pound-mass (lbs avoirdupois)	4.535 924 x E -1	kilogram (kg)
pound-mass-foot^2 (moment of inertia)	4.214 011 x E -2	kilogram-meter^2 (kg.m^2)
pound-mass/foot^3	1.601 846 x E +1	kilogram/meter^3 (kg/m^3)
rad (radiation dose absorbed)	1.000 000 x E -2	**Gray (Gy)
roentgen	2.579 760 x E -4	coulomb/kilogram (C/kg)
shake	1.000 000 x E -8	second (s)
slug	1.459 390 x E +1	kilogram (kg)
torr (mm Hg, 0°C)	1.333 22 x E -1	kilo pascal (kPa)

*The becquerel (Bq) is the SI unit of radioactivity; 1 Bq = 1 event/s.
**The Gray (Gy) is the SI unit of absorbed radiation.

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SECTION 1

INTRODUCTION

1.1 GENERAL.

This is a summary report of tests conducted at Waterways Experiment Station (WES) during the period June 23 to 25, 1992, on portable static wheel load scales acquired from PAT Equipment Corporation of Chambersburg, PA. A description of the test methodology and the analytical approach utilized to evaluate the data sets gathered in the field are included in this report. Common field problems that were encountered during the collection of the data and recommendations for future measurements and analysis of data are also provided.

The portable wheel load scales that were used were PAT MODEL SAW 10c scales. The PAT MODEL SAW 10c scale is a compact lightweight scale used for measurements of wheel load weights up to 20,000 lb or single axle weights up to 40,000 lb. For single axle weighing, two of the wheel load scales were connected by a standard 15-foot cable. When connected, the scales automatically sum the wheel weight for an axle load and allow for the observation of the single axle weight on either side of the test vehicle. The scale can be used on any normal road surface without special precautions, as indicated in the Technical Description and Operating Manual supplied with the scales. However, it is necessary to compensate for the height of the scales by placing dummy plates or ramps under the tires of the other vehicle axles to ensure all tires are at the same height as the weighing surface.

All of the tests were performed on a resin modified asphalt test section located adjacent to the Geotechnical Laboratory at WES. The pavement section provided a flat even surface on which test could be performed. Four vehicles were used with different numbers of axles: Jeep utility pickup truck - 2 axles, military transport (AT6X6) - 3 axles, GMC heavy equipment mobile transport truck - 4 axles, and 18 wheel tractor-trailer (3S2) - 5 axles. The parameters recorded in the field were temperature, time, date, weather conditions, number of axles per vehicle, tire pressure, driver's weight, and axle weight. The true weight of the vehicles was obtained using the Mississippi Department of Transportation (DOT) platform scales located on Interstate 20 east of Vicksburg.

The analysis of the data collected during this test series includes the calculation of statistical parameters such as mean, standard deviation, and percent of error. Some statistical inference using a test of hypotheses was performed by comparing the sample (axle weight of the individual trucks) to the total population (axle weights of all the vehicles).

1.2 PURPOSE.

The objective of the test was to estimate the number of tests that were required to determine if the portable static scales manufactured by PAT were capable of weighing multiaxle vehicles, over a wide range of loads, to an accuracy of ±1 percent of the gross vehicle weight.

1.3 SCOPE.

The test included the use of two scales, the PAT and the Mississippi DOT scale. The Mississippi DOT scale was assumed 100 percent accurate to evaluate the PAT scale accuracy. The field test included the weight of the vehicle axle using the PAT scales and total vehicle weight using the Mississippi DOT scale on a level and smooth surface. The sum of all the axles was considered as the total vehicle weight (or the sample weight) when the PAT scale was used. In addition, the possible vehicle weight difference caused by the fuel consumption was assumed insignificant. The number of observations gathered in the field was 30 for each vehicle axle using the PAT scale and 2 for each vehicle using the Mississippi scale. Four vehicles were used to represent the vehicle population of 2, 3, 4, and 5 axles. The vehicles were weighted with a load and then with half of that load. These samples were used to represent the vehicle weight population. This test was developed using the analysis and results of data acquired from a previous test conducted at WES on May 21 to 22, 1992, as a reference. The use of data collected from the previous test helped to avoid possible errors and solve logistic problems that occurred in the field. The statistical analysis included the normability assumption, the determination of a confidence interval that the results would be within ± 1 percent of the true gross vehicle weight, the determination of the number of runs needed to obtain 99 percent accuracy in the results, the calculation of the samples parameter such as mean, variance, standard deviation, coefficient of variation, percent of error, and test of hypothesis.

SECTION 2

PREVIOUS TESTS

2.1 TEST SUMMARY.

A previous test was performed at WES in May of 1992. The test purposes were to familiarize with the PAT scale use and setup, and to evaluate if the PAT scale replicability can changed with the weighing direction (north or south). Data for the test were obtained by passing test vehicles over the scales in two directions (north and south). However, only ten runs were collected for each vehicle in that test. The weight of the axle loads was calculated by averaging the individual wheel loads for the two directions. The results of the analysis of the data and the conclusions of the test can be found in Appendix A. The test results were used to design the test conducted in July 23-25, 1992 which evaluated the scales accuracy. The statistical analysis of the data shows that there is no significant difference between the data collected from the two directions (north and south). Assuming a level straight approach, the vehicles need only be weighed in one direction to save time in obtaining the data that represent the whole population.

The classification of the statistical size of the sample for each of the vehicles was a small sample since the number of samples taken was less than 30. Therefore, a small sample theory was used for the analysis. One significant result found was that the sample for each of the vehicles does not represent the entire population. This problem implies that the conclusions and recommendations that can be made using these samples were not reliable. The samples reliability were needed to estimate the number of tests that were required to determine if the portable static scales were capable of weighing multiaxle vehicles to an accuracy of ±1 percent of the gross vehicle weight.

2.2 STATISTICAL APPROACH.

To determine the number of tests required to achieve an accuracy of 1 percent, 2 percent, and 3 percent, a confidence level of 95 percent was selected. Equation 2.1 was used to calculate the number of observations, but instead of $Z_{\frac{\alpha}{2}}$ (for normal distribution, $n \geq 30$), the small sample distribution t was used in the previous test (Montgomery 1980, and Walpole and Myers 1972).

$$n = \left[\frac{Z_{\frac{\alpha}{2}}\ \sigma}{e} \right]^2 \tag{2.1}$$

where

n = sample size
$Z_{\frac{\alpha}{2}}$ = critical value or confidence coefficient
σ = standard deviation
e = error

This formula is applicable only if the deviation (σ) of the weight with respect to the average weight is known (population's variance). The lack of variance requires a preliminary sample to represent the population. A good representation of the population is found if the sample mean is equal to the population mean. Also, histograms and normal probability plots can be used to prove the normal condition of the samples. It was determined that the previous test did not meet this condition and the possible conclusions or recommendations based on this sample would be in error.

SECTION 3

DESCRIPTION OF THE TEST

3.1 GENERAL INFORMATION.

The weight data gathered in the field was accompanied by other general information which included date, time, atmospheric conditions, temperature, tire pressure, type of vehicle, number of axles, and load (the vehicle and driver's weight). This information helps to explain some of the abnormal conditions or problems that can be found in the data. The information will also be relevant for future analysis of the data. In general, the conditions during the test were similar, sunny and humid in the morning and very hot in the afternoon with temperatures exceeding 100°F. Four vehicles were used with different numbers of axles: Jeep utility pickup truck - 2 axles, military transport (AT6X6) - 3 axles, GMC heavy equipment mobile transport truck - 4 axles, and 18 wheel tractor-trailer (3S2) - 5 axles (see Figures 3-1 to 3-4). The tire pressures and the loads in the vehicles varied with the type of test vehicle. The measurements were divided into two parts as the vehicles were weighed first fully loaded and then at half of its original load. The loads in the vehicles consisted of blocks of lead and steel equivalent to 2,000 and 1,000 lb, respectively (see Table 3-1). The jeep was loaded with one block of steel, the AT6X6 with 8 lead blocks, the GMC with 16 lead blocks and the 3S2 with 16 lead blocks. The unloaded case consisted of a reduction to half the previous load. Appendix C shows the maximum and minimum weight for each axle of the vehicle. In addition, Table 3-2 shows the total weight of the vehicles for the load and unload cases; a range of minimum and maximum load occurred due to fluctuations in the Mississippi's platform scale. One special test was included to verify the axle height effect when the vehicles were weighed. The sample size for this test was 15 observations for unloaded and loaded conditions and the vehicle differs in height with respect to the scales. Only the adjacent axles to the scale had the same height as the scales. The vehicle used for this test was the GMC truck and the results were represented along the report by GMC_s. When all axles were blocked (30 runs) the notation used to represent the results was GMC.

Table 3-1. Vehicle weight conditions.

VEHICLE	LOADED lb	UNLOADED lb	BLOCK
Jeep	1,000	0	Steel
AT6X6	16,000	8,000	Lead
GMC	32,000	16,000	Lead
3S2	32,000	16,000	Lead

Table 3-2. Total vehicle weight using PAT scales.

VEHICLE	LOAD, lb		UNLOAD, lb	
	MAXIMUM	MINIMUM	MAXIMUM	MINIMUM
JEEP	5,240	5,160	4,220	4,140
AT6X6	35,720	34,900	27,540	26,820
GMC[1]	80,880	79,660	64,640	64,200
GMC_S[2]	80,460	79,300	64,100	63,560
3S2	70,560	68,960	53,660	52,540

[1] All axles were blocked (30 runs)

[2] Only axles adjacent to the scale were blocked (15 runs)

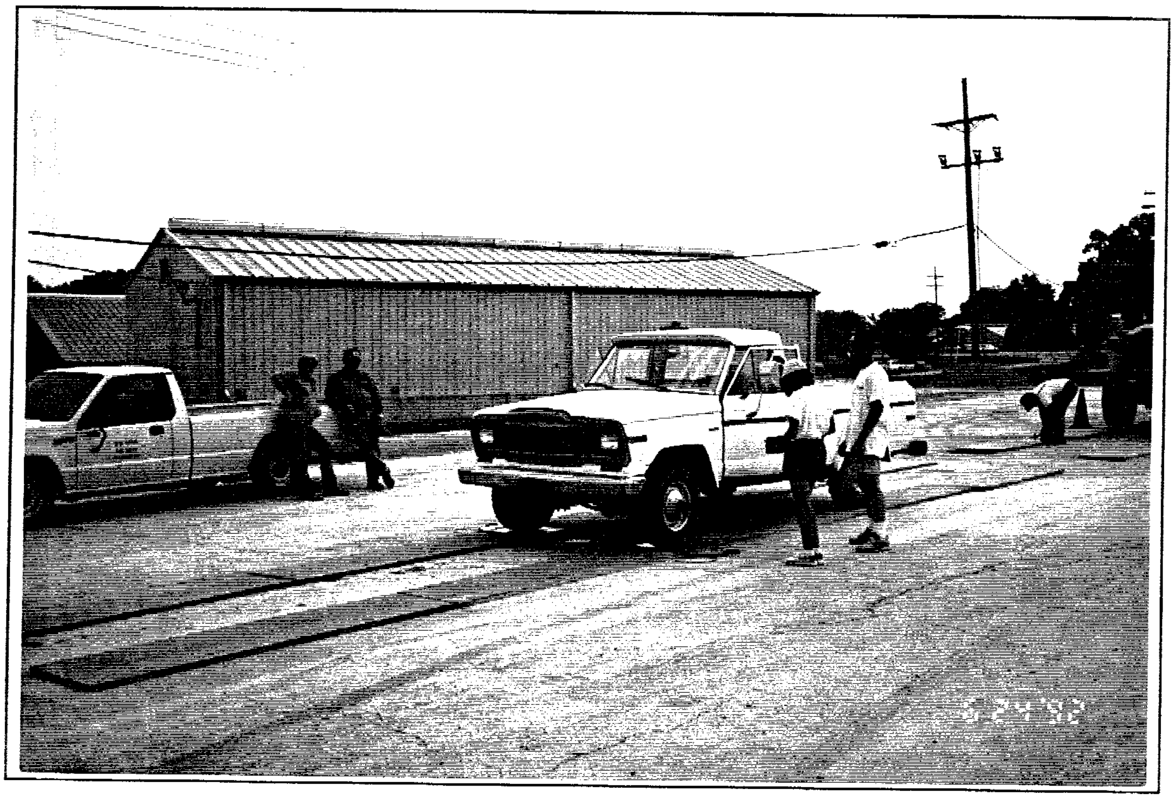

Figure 3-1. Jeep pickup truck, 2 axles.

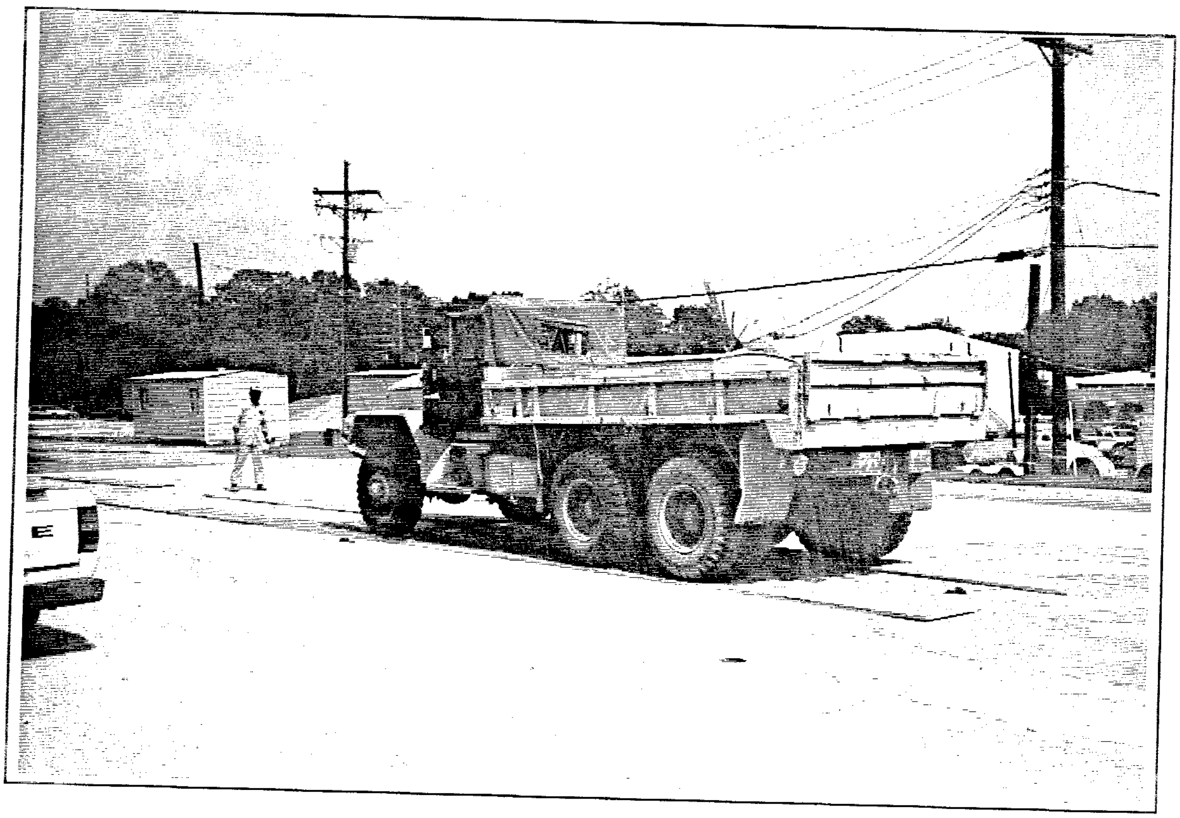

Figure 3-2. Military transport truck (AT6X6), 3 axles.

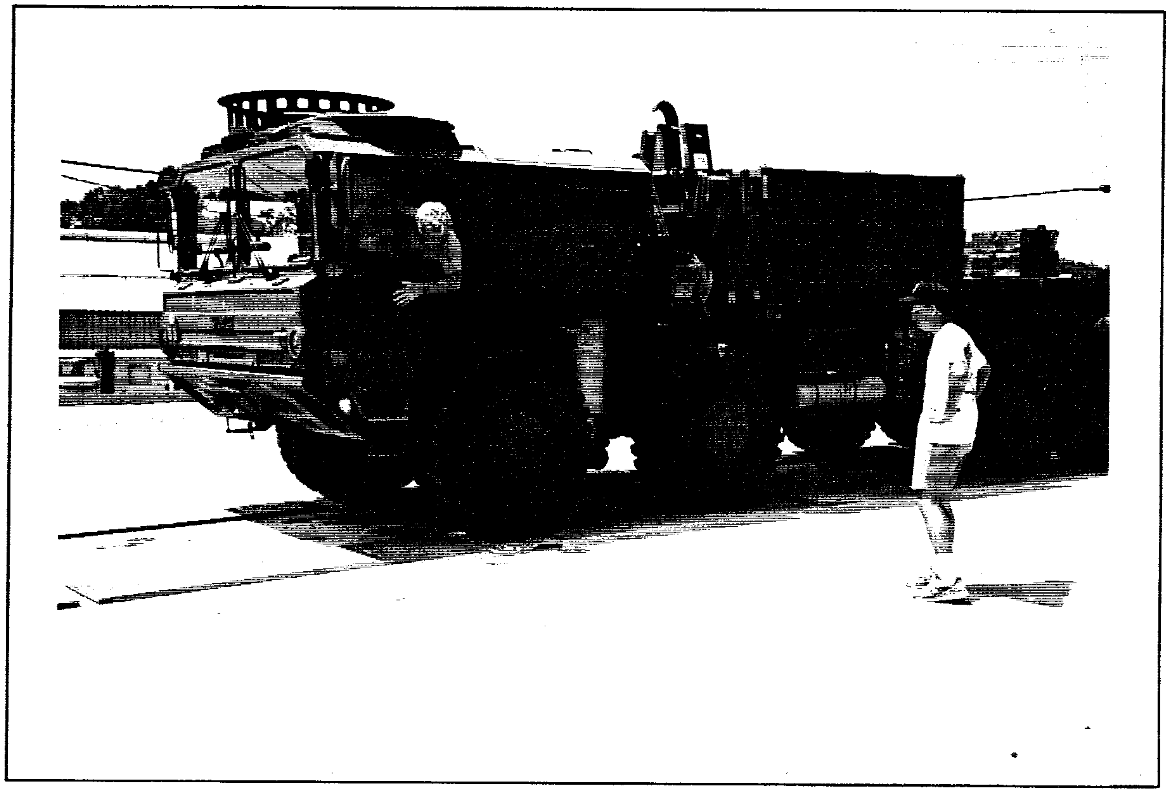

Figure 3-3. GMC transport truck, 4 axles.

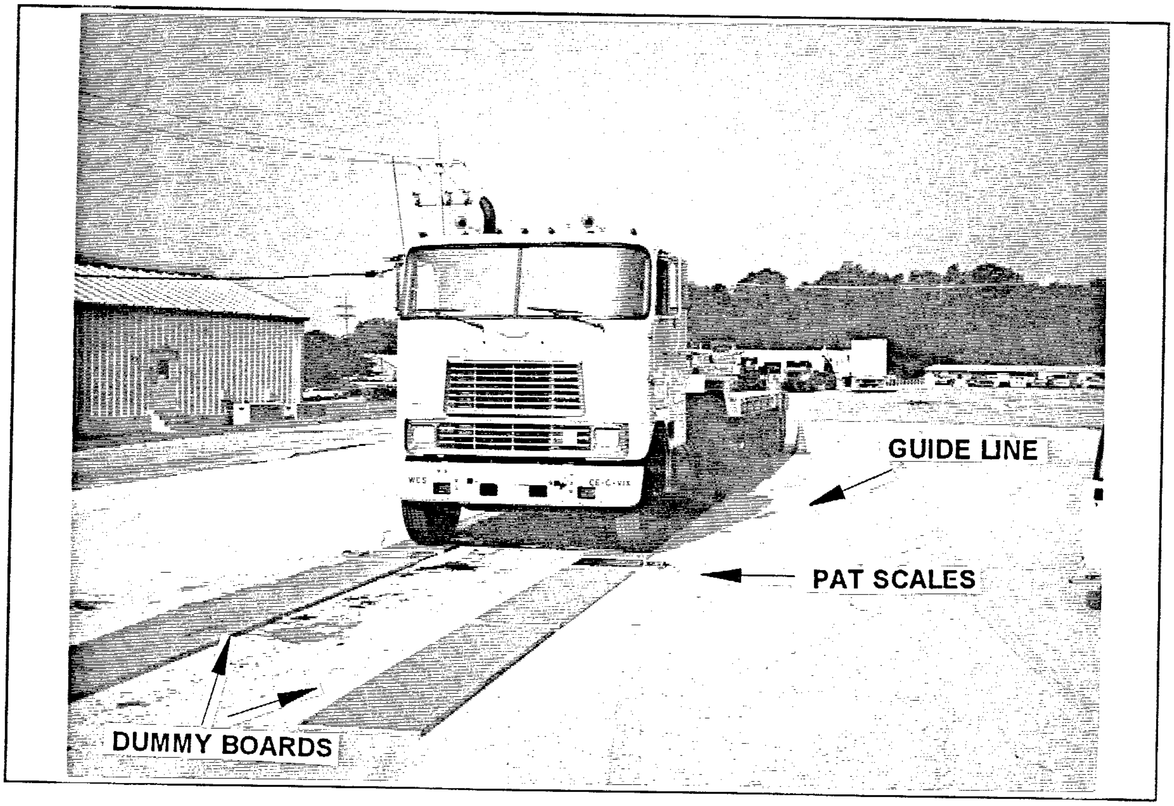

Figure 3-4. Tractor trailer truck (3S2), 5 axles.

3.2 PROCEDURE.

Testing procedures were clearly defined and important warnings were specified to avoid error in data collection. Some of these included: the load in the vehicle should remain in the same place during the entire testing procedure, the area where the scale is placed should be clean and level, the height of all of the wheels of the vehicle should be at the same height as the scale, and the tires should be centered on the scale during testing.

The correct operation of the scales and the charge of the scale's batteries were checked each day before tests began. The test area was cleaned and guides were painted on the test surface to help drivers maintain vehicle alignment and position. The fuel in the trucks and tire pressures were verified each morning. Special forms to record data for each type of vehicle were developed which helped to better organize the data (see Appendix B). The order in which the vehicles were weighed was random but the first sample for each vehicle was for the loaded condition. The number of runs for each vehicle was 30 for each loading condition (loaded and unloaded). In addition, to compensate for the scale height, leveling boards were used. Another 15 runs were taken for the GMC truck for the loaded and unloaded condition with leveling boards placed only under the axle adjacent to the scale (the scale height was not compensated). The test was completed in three days, starting at 7:00 am and at 5:30 pm. The schedule for the third day was from 7:00 am to 12:00 pm.

3.3 WEIGHT OF THE VEHICLES.

All of the trucks were weighed at the beginning of the first set of samples (loaded and half-loaded) on the Mississippi Scales. The Mississippi scales are located on the east- and west-bound lanes of Interstate 20 at Vicksburg, and the scales are part of a permanent weigh station (see Figure 3-5). The average weight from both scales was used as the true weight of the vehicle (or gross vehicle weight). The weigh station consists of a Weigh-In-Motion (WIM) system that can weigh vehicles without traffic interruption and static scales. The static scale involves bending plate technology and its objective is to make accurate measurements of vehicle weights. The individual axle loads, as well as the total weight of the vehicle, are calculated. Vehicles which are detected as being outside the load limits are directed to the static scale where a precise check is made. Those within the load limits may proceed on their journeys without additional interruption. For the purpose of this investigation, the weight information of the Mississippi static scale was only considered.

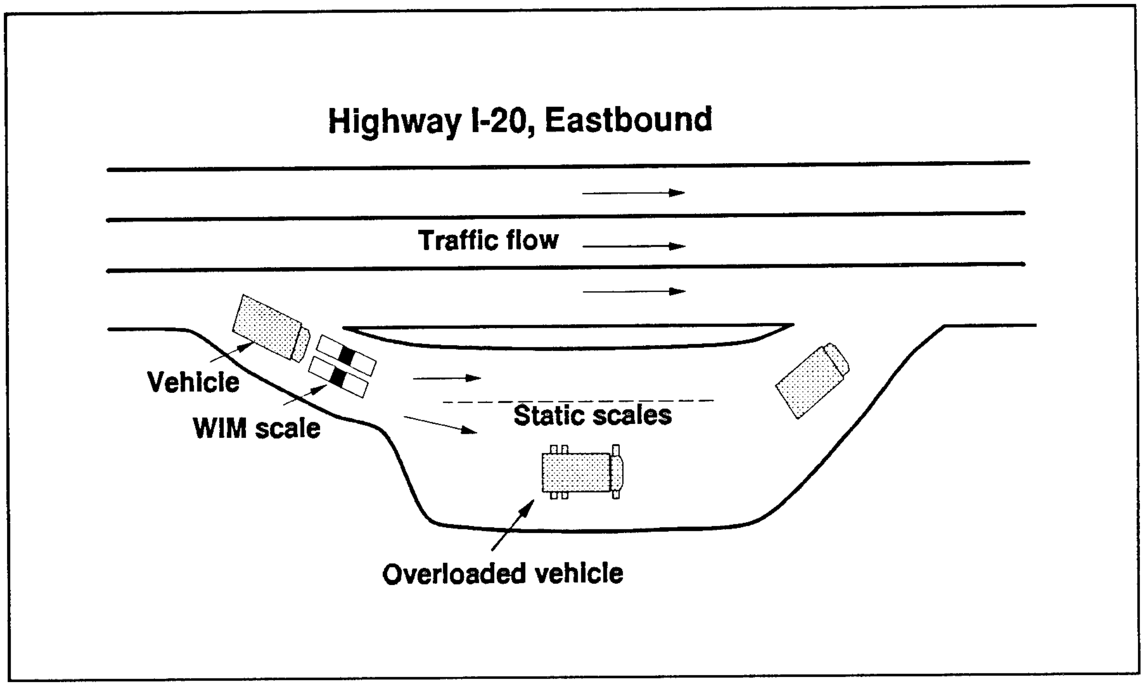

Figure 3-5. Mississippi permanent weigh station layout.

Figure 3-6 shows the placement of leveling boards when the number of axles increase. Figure 3-7 shows the position of the PAT portable static scales and the leveling boards on the test section. It is important to note that the Technical Description and Operating Manual provided with the PAT scale shows a different layout for the leveling boards. The positioning of the boards recommended in the manual gave good results for light and non-articulated vehicles. On the articulated vehicle (3S2) it was difficult to keep the vehicle in alignment and position as the vehicle was moving across the scale. In other cases, it is difficult to maintain the trucks in position because the individual leveling boards had a tendency to creep as the driver applied power to position the vehicle over the leveling boards. In addition, the scale manual indicates that leveling boards should be used in all cases for height compensation when the number of sets of scales is less than the number of axles. This implies that the board position should not affect the results. Before starting the test, several runs with the leveling boards placed in the standard configuration were examined. These were then compared with runs using leveling boards in the wide position; no differences were found between the weights.

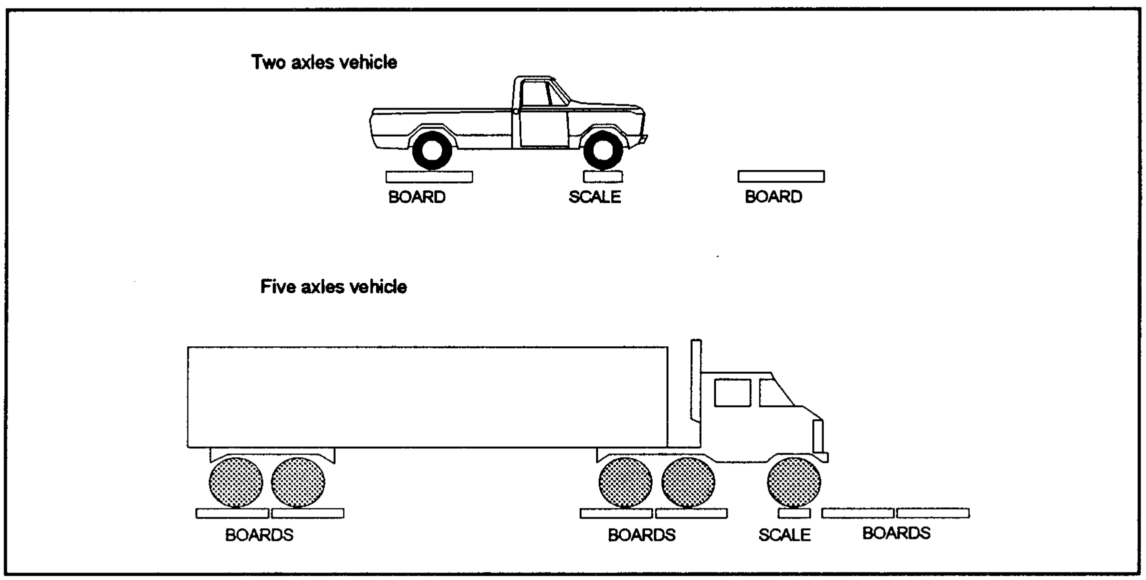

Figure 3-6. Placement of leveling boards as the axles increase.

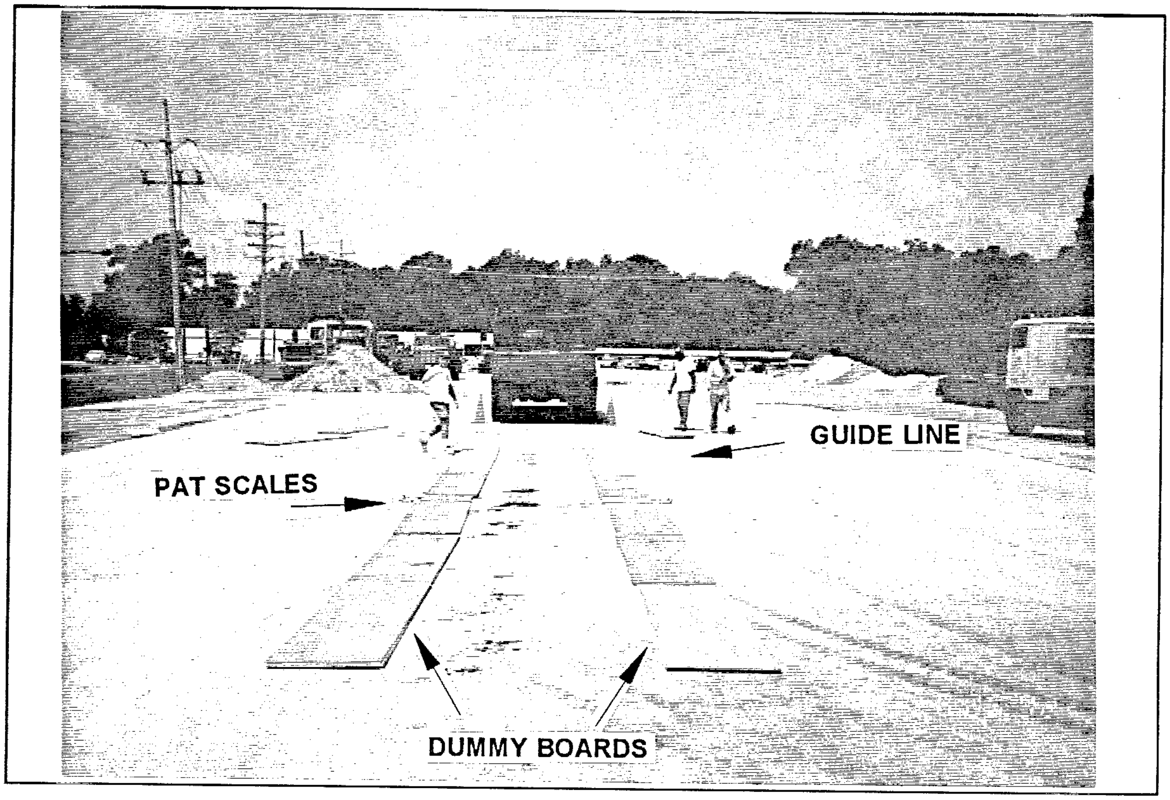

Figure 3-7. Scales and board positions.

Initially, the driver would pull up and place the first axle of the vehicle on the center of the scale. Positions were then marked for leveling board placement for the remaining axles. This procedure was followed for each vehicle, ensuring correct placement of leveling boards for each run. Testing for the Jeep went relatively quickly as it had only two axles that could easily be positioned over the scales. The GMC and AT6X6 trucks took more time as they were more difficult to align and center over the scales. These three vehicles were then moved forward and backward across the scales and leveling boards, stopping to obtain each axle's weight for each run. If the alignment of the vehicles was not perpendicular to the direction of travel, the readings were stopped, the vehicles realigned, and measurement retaken. If the 3S2 truck was not correctly aligned for the measurement, weighing was suspended and the vehicle was required to make another pass due to the difficulty in backing the vehicle over the scales. In addition, the driver needed more time to align the cab and the trailer with the scales.

SECTION 4

PROBLEMS IN THE FIELD

4.1 MECHANICAL PROBLEMS.

Some mechanical problems were encountered in the field at the beginning of the test and also during the test. The 3S2 truck was chosen to start the test but encountered some mechanical problems. The 3S2 truck brake system was not working properly. As a result, this situation caused wrong weigh reading because the truck could not be stopped in the right place. The PAT scales accuracy was affected and the number of runs increased by this condition.

Mechanical problems on a multiaxle vehicle affected the PAT scale measures, and the results could show erroneous conclusion on that vehicle type. The use of PAT scales for multiaxle vehicle could be questionable but caution and care were the main tool to detect and avoid possible error in the weighing process. The Jeep was then substituted as the lead test vehicle and the 3S2 was repaired.

4.2 EQUIPMENT PROBLEMS.

The leveling boards consisted of two wooden panels 1 inch and 1/2 inch in thickness. These boards were used as dummy plates to raise adjacent axles to the PAT scales in order to obtain a level surface with the PAT scale, thus all the wheels of the vehicle were at the same height. The two panels however, had a tendency to slide apart and the entire assembly would move across the concrete surface. To fix the problem, the panels were nailed together. The problem still remained because the weight of the vehicle caused the sections to separate and move. To minimize the movement between the leveling boards and the concrete surface, the vehicles were required to approach the leveling boards at a very low speed. These conditions were also observed when the vehicle's brakes were applied. Also observed during the tests were deflections in the leveling boards due to applied load, as well as cracking of the edges.

The Technical Description and Operating Manual warning about the positioning of the boards to keep the vehicle in alignment and position as it is moving across the scale to avoid weighing errors. In addition, the scale manual indicates that leveling boards should be used in all cases for height compensation when the number of sets of scales is less than the number of axles to avoid difference in the measurements. The correct placement of the axles over the scale was affected by the tendency of the leveling board to slide apart. The alignment of the vehicles needed to be perpendicular to the direction of travel to obtain accurate weighing. When the run did not accomplished with this requirement, the vehicle was required to make another pass. The tendency to slide apart of the leveling boards, and it movements across the surface implied additional time to align the cab and the trailer with the scales, increase the number of wrong runs, and lack of accuracy of the scales.

SECTION 5

ANALYSIS OF THE DATA

5.1 FIELD ANALYSIS.

For each run, the data were recorded and analyzed to detect if significant differences were observed from run to run. If the value between the runs was significantly different, the positioning and the alignment of the vehicle were checked.

5.2 STATISTICAL ANALYSIS.

5.2.1 Parameter.

The population of interest in this test was the total weight of the vehicle, which is the sum of all individual axles weighted. Two different samples of 30 runs were gathered for each vehicle type. The first set of data applies to the truck loaded and the second set applies to the vehicle at half of the original load. The mean, standard deviation, variance, and percent of the error between the true weight and the observed weight were calculated for each sample (e.g., Dixon and Massey 1957 and Spiegel 1961). See Appendix C. Tables 5-1 and 5-2 show the summary of these parameters for the loaded and unloaded conditions. The errors between the means are small, which indicates that the sample has similar characteristics to the population. Thus, the PAT shows precision in its measurements.

The error for the regular GMC tests and the separate GMC tests (in which only axles adjacent to the weighed axle were leveled, denoted in the tables as GMC_S) increased by 0.62 and 0.78 percent for the fully and partially loaded test, respectively. The conditions for both tests were similar; the only difference was the number of runs. In the Tables 5-1 and 5-2 the differences in error for heavy vehicles can be seen. This error can be caused by the height difference of the truck wheels not compensated for.

Table 5-1. Summary of the samples' parameters (fully loaded).

VEHICLE	GROSS WEIGHT lb[1]	SAMPLE WEIGHT lb[2]	VARIANCE σ^2	STANDARD DEVIATION σ	COEFFICIENT OF VARIATION	PERCENT ERROR %
Jeep	5,160	5,203	737	27.2	0.52	0.83
AT6X6	35,060	35,308	39,871	199.7	0.57	0.71
GMC	80,890	80,267	92,096	303.5	0.39	0.77
GMC_S	80,890	79,764	10,5383	324.6	0.41	1.39
3S2	69,260	69,691	12,3026	350.7	0.50	0.62

1 Vehicles weighted using the Mississippi scale.
2 Vehicles weighted using the PAT scale.

Table 5-2. Summary of the samples' parameters (half loaded).

VEHICLE	GROSS WEIGHT lb	SAMPLE WEIGHT lb	VARIANCE σ^2	STANDARD DEVIATION σ	COEFFICIENT OF VARIATION	PERCENT ERROR %
Jeep	4,170	4,172	292	17.1	0.41	0.05
AT6X6	27,150	27,150	23,883	154.5	0.57	0.00
GMC	64,700	64,081	3,356,302	1,832.0	2.87	0.96
GMC_S	80,890	63,911	18164	134.8	0.21	1.22
3S2	52,860	53,135	53377	231.0	0.43	0.52

5.2.2 Normability Test.

Some assumption about the sample distribution must be made in order to perform a statistical analysis. One typical assumption is that the distribution is normal. Figures 5-1 and 5-2 show the frequency histograms for 30 measurements of the weights of the 3S2 vehicle. The frequency histograms indicate a bell-shaped distribution; hence, the assumption of normability seems reasonable. The measured weights are displaced to the right of the true weight. The normal probability plots for the 3S2 truck show the sample values near the diagonal line (see Figures 5-3 and 5-4). This test also supports the normability assumption of the samples.

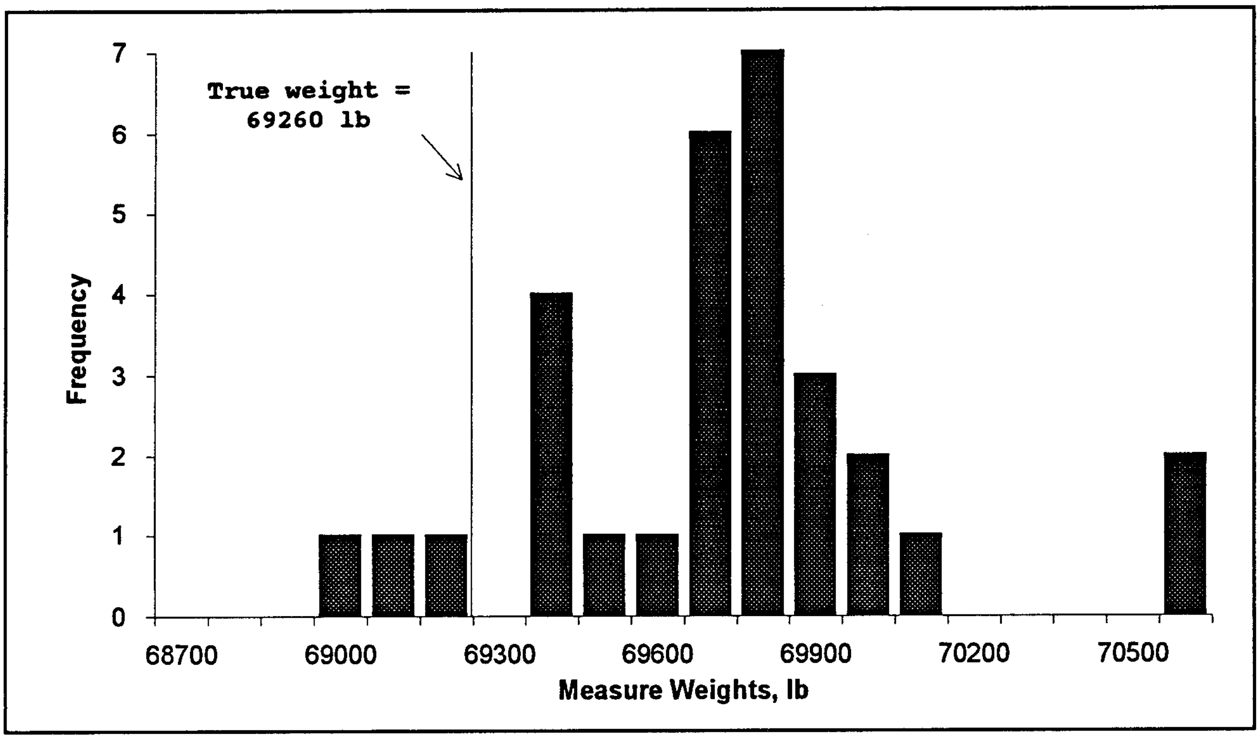

Figure 5-1. Frequency histogram, 3S2 truck (loaded).

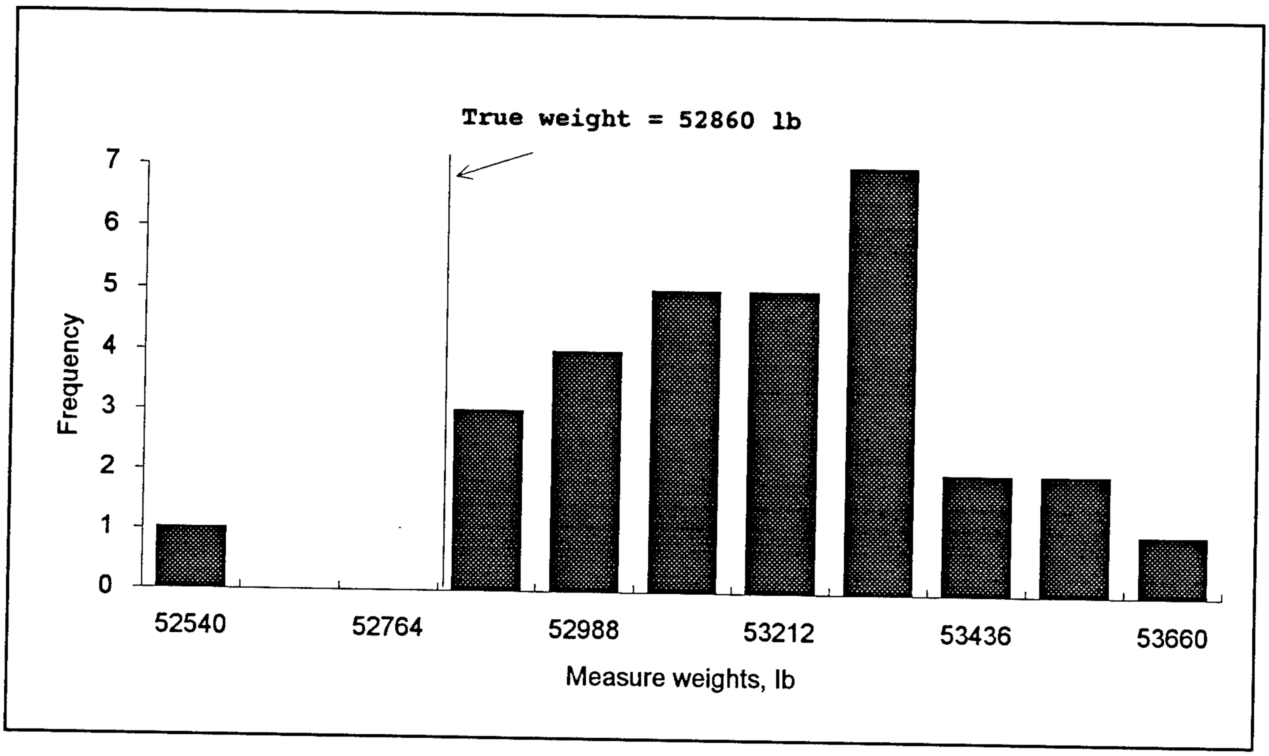

Figure 5-2. Frequency histogram, 3S2 truck (unloaded).

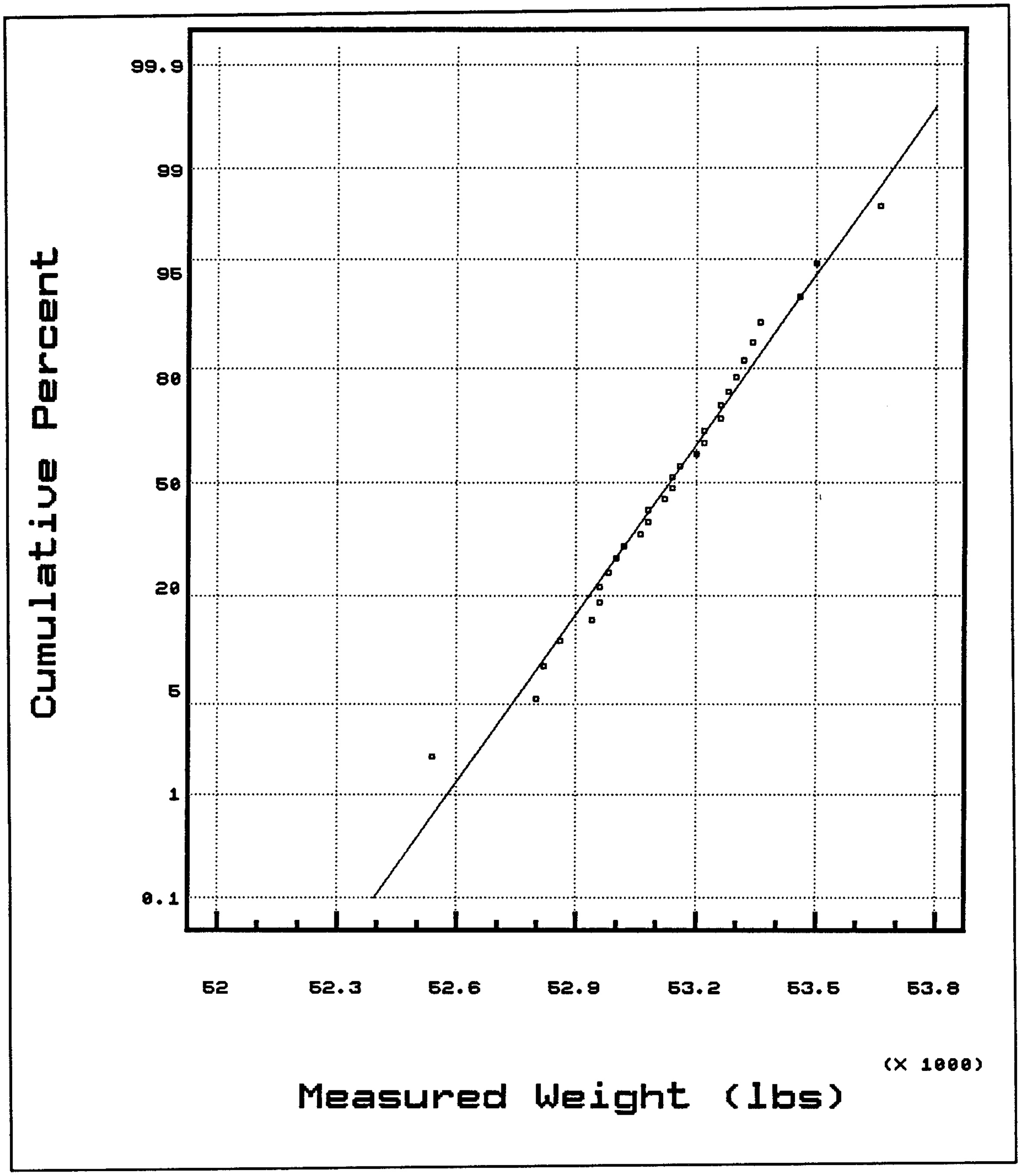

Figure 5-3. Normal probability plot, 3S2 loaded.

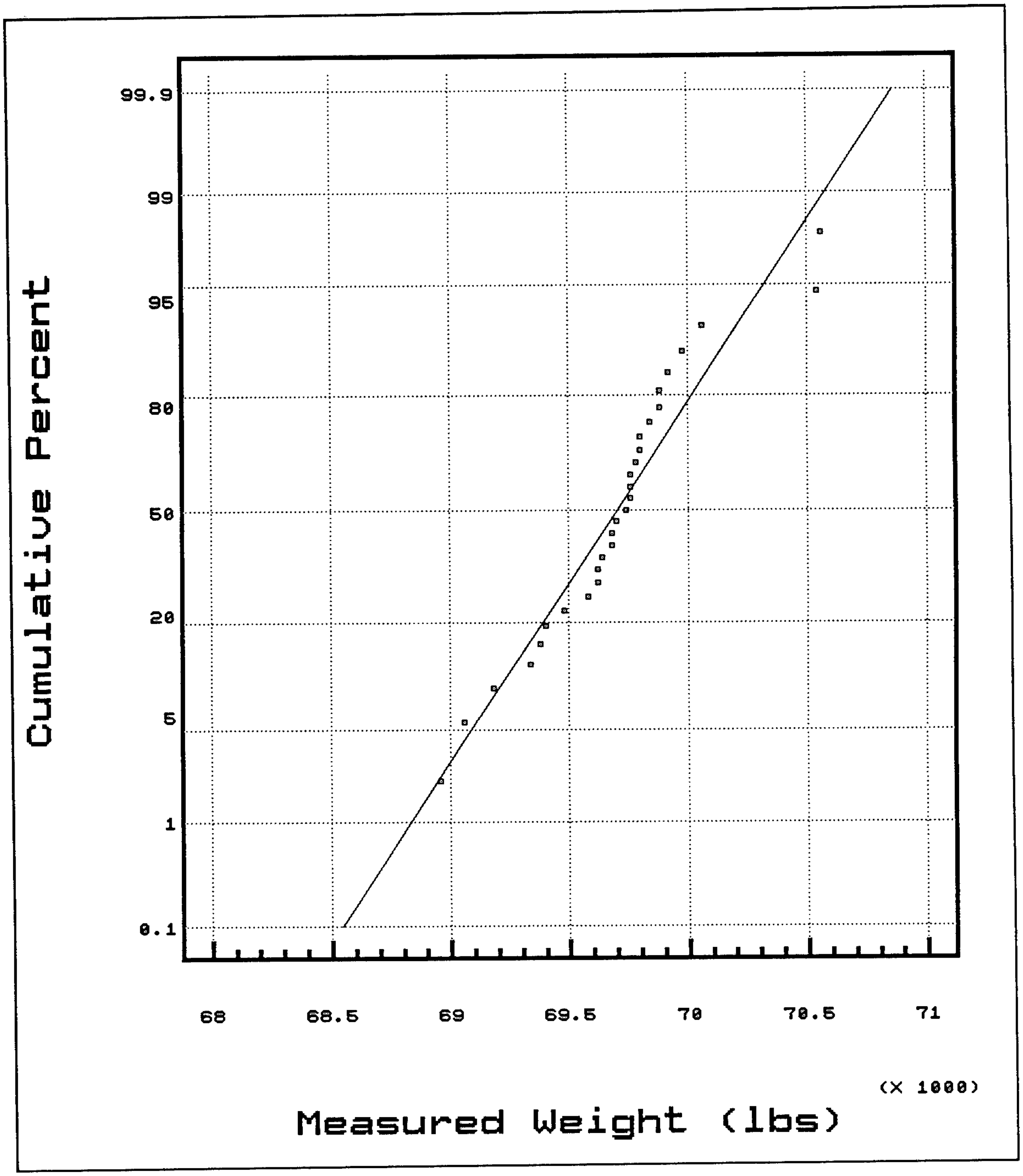

Figure 5-4. Normal probability plot 3S2 unloaded.

5.2.3 Detailed Error.

Appendix D shows two tables that show the difference between the true weight and the measured weight of the 3S2 for each of the 30 measurements, in both the loaded and unloaded conditions. These differences indicate the accuracy of the scales because the variation in all cases are less than 1 percent. The difference between the true and measured weight, or error, can be used to evaluate the accuracy of the sample data. The principal objective of this test may be achieved by conducting a statistical analysis on the error. A summary of the results of this analysis appears in Tables 5-3 and 5-4.

Table 5-3. Statistical parameters for the error (fully loaded).

VEHICLE	ERROR		
	MEAN μ	STANDARD DEVIATION σ	VARIANCE σ^2
Jeep	0.008269	0.005263	0.000028
AT6X6	0.007081	0.005695	0.000032
GMC	-0.007698	0.003752	0.000014
GMC_S	-0.031920	0.004013	0.000016
3S2	0.006228	0.005064	0.000026

Table 5-4. Statistical parameters for the error (half loaded).

VEHICLE	ERROR		
	MEAN μ	STANDARD DEVIATION σ	VARIANCE σ^2
Jeep	0.00480	0.004104	0.000017
AT6X6	-0.00000	0.005692	0.000032
GMC	-0.00441	0.001752	0.000003
GMC_S	-0.01220	0.002083	0.000004
3S2	0.005196	0.004371	0.000019

5.2.4 Population's Mean Versus Sample's Mean.

The test of the hypothesis is another tool to verify if the samples are acceptable. According to Walpole and Myers (1972), the main purpose in selecting samples is to predict information about the unknown population parameters. Statistical inference should then prove if the mean of the sample is equal to the population's mean. Appendix C shows the results of the test of the hypothesis for each sample. For the loaded case, the conclusion was that the sample for each vehicle does not represent the population of interest as shown Table 5-5. For the unloaded case, the conclusion was slip. The samples of the Jeep and AT6X6 vehicles represent the population, but the samples of the GMC and 3S2 vehicles do not represent the population of interest. Using the Analysis of Variance (ANOVA) test, the conclusion for the Jeep, AT6X6, and 3S2 vehicles was that the sample does not represent the population. Therefore, other types of statistical analysis (such as normability test, and histograms) were conducted in order to know more about the characteristics of the population. The results of these tests indicated that the sample represented the characteristics of the population.

Table 5-5. Test of the hypothesis for the population and sample.

VEHICLE	MEAN		VARIANCE	
	LOADED	UNLOADED	LOADED	UNLOADED
Jeep	Reject	Accept	Reject	Reject
AT6X6	Reject	Accept	Reject	Accept
GMC	Reject	Reject	Reject	Reject
GMC_s	Reject	Reject	Accept	Reject
3S2	Reject	Reject	Reject	Reject

5.2.5 Number of Runs.

To determine the number of runs necessary to obtain an accuracy of 1 percent, 2 percent, and 3 percent at a confidence level of 95 percent equation 2.1 was used once the statistical hypothesis that was present in the previous paragraph was validated using the normability and histogram plots. Table 5-6 shows the results for each vehicle tested. Only one run is required to obtain 1 percent accuracy for the AT6X6, GMC, and 3S2 trucks. Appendix E shows the variation in the number of runs when the accuracy varies from 1 percent, 2 percent and 3 percent (Mace 1964).

Table 5-6. Number of runs for 1 percent accuracy at 95 percent confidence level, first approach.

VEHICLE	NUMBER OF RUNS 1% accuracy	
	Full Load	Half Load
Jeep	2 (1.064)	1 (0.646)
AT6X6	1 (0.985)	1 (0.734)
GMC	1 (0.541)	1 (0.118)
GMC_S	1 (0.619)	1 (0.167)
3S2	2 (1.246)	2 (1.245)

Using the results of the deviation between the true and measured weight, the number of runs can be calculated in a similar way. The error shows the difference of the measured weight with respect to the true weight. This variable can be use to determine the number of runs for a 95 percent confidence level and the accuracy desired (Appendix E). Tables 5-7 and 5-8 show the result for the number of runs. Both approaches do not show significant difference in the results and either approach is acceptable. The Jeep and AT6X6 truck need two runs for 1 percent accuracy but the GMC and 3S2 trucks require one run. Again, only one run is required to obtain 2 and 3 percent accuracy for all the vehicle.

Table 5-7. Number of runs needed to obtain a 95 percent confidence level (loaded), second approach.

VEHICLE	NUMBER OF RUNS Accuracy		
	1 percent	2 percent	3 percent
Jeep	2 (1.064)	1 (0.266)	1 (0.118)
AT6X6	2 (1.256)	1 (0.312)	1 (0.138)
GMC	1 (0.541)	1 (0.135)	1 (0.060)
GMC_S	1 (0.619)	1 (0.155)	1 (0.069)
3S2	1 (0.985)	1 (0.246)	1 (0.109)

Table 5-8. Number of runs needed to obtain a 95 percent confidence level (unloaded), second approach.

VEHICLE	NUMBER OF RUNS Accuracy		
	1 percent	2 percent	3 percent
JEEP	1 (0.650)	1 (0.160)	1 (0.070)
AT6X6	2 (1.240)	1 (0.310)	1 (0.140)
GMC	1 (0.120)	1 (0.030)	1 (0.010)
GMC_S	1 (0.170)	1 (0.040)	1 (0.020)
3S2	1 (0.730)	1 (0.180)	1 (0.080)

5.2.6 Confidence Intervals.

The confidence intervals' length indicates the precision or accuracy of an estimate (average of sample's mean). Also, it is better to have a short interval with a high degree of confidence. Equation 5.1 shows the expression used to calculate the intervals. Appendix F shows the 95 percent confidence level for all the samples. The range of confidence intervals for the mean are shorter than those for the variance.

$$\mu_{sample} - Z_{\frac{\alpha}{2}} \frac{\sigma}{\sqrt{n}} < \mu < \mu_{sample} + Z_{\frac{\alpha}{2}} \frac{\sigma}{\sqrt{n}} \qquad (5.1)$$

where

μ_{sample} = mean of a sample

$Z_{\frac{\alpha}{2}}$ = value of the standard normal distribution (critical value)

σ = standard deviation of the sample

n = sample size

Table 5-9 shows the mean and standard deviation confidence interval for each vehicle. The confidence intervals range for the PAT scales weighing measurements are short indicating that the scales have high degree of confidence or accuracy in the prediction of vehicle weight. When the scale is not available, the vehicle weight can be estimated using the intervals values. The intervals values can be used only if the conditions of the test are similar.

Table 5-9. Confidence intervals.

	CONFIDENCE INTERVALS RANGE[1]	
VEHICLE	**MEAN μ**	**STANDARD DEVIATION σ^2**
Jeep	19.4	6,796.5
AT6X6	251.0	1,133,839.0
GMC	217.2	848,782.6
GMC_S	232.3	971,237.1
3S2	142.9	367,460.3

[1] $Range = 2 Z_{\frac{\alpha}{2}} \frac{\sigma}{\sqrt{n}}$

5.2.7 Analysis for the Loaded and Unloaded Cases.

The loaded and unloaded samples for each vehicle were compared. Statistical inferences about the mean and the variance for both samples were analyzed to see if any significant differences exist between the samples (see Appendix C). Tests of the hypothesis of equality of the means and variance of the loaded and unloaded cases show that both samples are different. The ANOVA was used to compare the equality of the samples' mean, while Cochran's test was used for the variance.

SECTION 6

RESULTS

6.1 CHECK OF DATA.

The continuous check of data gathered avoided an increase in the deviation between the runs. The results of that action can be observed in the percent error. The error for each sample was less than 2 percent which indicates that the samples are reliable. For the set of partially-loaded tests, the percent error was less than those for the fully loaded case. The heavy vehicles present an increase in error as seen in Tables 5-1 and 5-2. The error fluctuates from 0.77 to 1.39 for the fully loaded case, and from 0 to 1.22 for the unloaded case.

All the samples gathered demonstrated adequate populations. Once this affirmation was verified, the number of runs needed for most cases was 1. A wide range for the confidence interval of the variance was obtained, but for the mean the interval is narrow (see Table 5-9).

6.2 DIFFERENCES.

Significant differences existed between the unloaded and loaded samples. For most cases the hypothesis that tests the mean between both conditions was rejected. It is evident that the difference in weight implies that the populations are not similar. For the AT6X6 truck the results in variance for both samples are equal. In the special test for the GMC, the ANOVA analysis shows that the sample means are equal. This result can be caused by two main factors. First, the sample size for this test was 15 observations for unloaded and loaded conditions. Second, the vehicle differs in height with respect to the scales. Only the adjacent axles to the scale had the same height as the scales.

The difference between the true and measured weights give a better estimate of the number of runs. The number of runs calculated in the two case (error and the sample) are similar. In both analyses the results are consistent for the loaded and unloaded test.

SECTION 7

CONCLUSIONS AND RECOMMENDATIONS

7.1 CONCLUSIONS.

a. PAT scales accuracy - The PAT SAW 10c portable static scales were capable of weighing multiaxle vehicle, over a wide range of loads (Table 3-1), to an accuracy of ±1 percent of the gross vehicle weight. The percent of error between the gross weight and the sample weight fluctuated from 0.83 for the Jeep to 0.62 for the 3S2 truck, showing error less than 1 percent. The number of runs was less or equal to 2 runs. The scales precision can be showed by the consistent weighing measures (Figure 5-1 and 5-2). Also, the confidence intervals range for the PAT scales weighing measurements indicate that the scales have high degree of confidence in the prediction of vehicle weight.

b. Portable static scale data acquisition - The research proposes guidelines for data acquisition using the portable static scales. The guidelines were used in the field test showing a reduction of time and effort needed to weigh vehicles. The number of observations needed for the 1 percent accuracy sample was determined prior to the field test. Once the scales and the boards were installed the data acquisition was a repetitive activity. For this particular test, an accuracy of 1 percent at a 95 percent confidence level can be obtained with the four test vehicles if care is taken with respect to blocking, position of the axles on the PAT scale, and alignment of the vehicle.

c. Loaded versus unloaded - There does not appear a significant difference between the loaded and unloaded conditions when determining the number of runs with an accuracy of 1 percent at 95 percent confidence level. The percent of errors for the PAT data are greater for loaded vehicles than for the unloaded vehicles. The PAT scales sensitivity due to the load conditions could be attributed to the vehicle dynamic mechanism (spring, shock absorbers, etc.).

d. Number of test - Small samples can represent the population if the data are gathered with special care. The sample size needed to obtain the desired precision does not need to be large. Better results can be obtained by studying typical behavior of a particular vehicle using old data and information. The sample size (number of tests) varied between 1 to 2 tests. This conclusion supported that the portable static scales were capable of weighing multiaxle vehicles to an accuracy of ±1 percent of the gross vehicle weight. In addition, this implies less time and less vehicle operating cost on the field with the desired accuracy in the results.

e. Axles height difference - The special test for the GMC truck (GMC_s) shows the results when the vehicle is not level or the axles are not in line with the axle over the PAT scales. The results indicate that the vehicle axles need to be at the same height as the axle over the scales using dummy boards. This compensation can reduce the error in the measurement because the magnitude of dynamic and diagonal forces will be less.

7.2 RECOMMENDATIONS AND COMMENTS.

a. This PAT SAW 10c scales can be used for measurements of wheel load weights up to 20,000 lb or single axle weights up to 40,000 lb. It is recommended to evaluate the accuracy of the scales with other type of vehicles. For example, the scales can be used to weight aircraft that do not exceed the previous scale limits.

b. Additional investigation needs to be conducted on the scales when the testing site geometry, environmental, and surface conditions are different from the manufacturer recommendations. For example, the surface can be unpaved or paved with a 2 percent slope. On the other hand, extreme temperatures may affect the scale accuracy. An experiment could be designed to evaluate how the environmental conditions can affect the number of test and the scale accuracy.

c. The leveling boards had a tendency to slip in most cases. Drivers should avoid abrupt stops and starts which cause slippage of the leveling boards. A literature review could be useful to provide information about the leveling board for future studies. The adequate leveling board can avoid inaccuracy in the process.

d. The next observations explain few situations which prolonged the field test and affected the number of test that were required to determine if the scales were capable of weighing multiaxle vehicles to a desire accuracy. First, the drivers need more time to center wheels over the dummy boards because they are narrow. Using wider boards made of some other material can help to reduce time in data collection and error in the data. Second, marks were put on the scale in order to center the tires when testing the vehicles, this helped obtain more accuracy in the data. Third, vehicles with automatic transmissions are easier to control. Finally, a review of the statistical concepts may help in the field; for example, by having some idea what the approximate deviation between the sample observations that can be tolerated will help to identify outlier values in the data that would lead to errors in the sample predictions.

SECTION 8

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APPENDIX A

PREVIOUS PAT DATA ANALYSIS

A.1 INTRODUCTION.

As mention previously, the test objectives were to familiarize with the PAT scale use and setup, and to evaluate if the PAT scale replicability can changed with the weighing direction (north or south). Only ten runs were collected for each vehicle in that test. The test results were used to design the test conducted in July 23-25, 1992 which evaluated the scales accuracy. The statistical analysis of the data shows that there is no significant difference between the data collected from the two directions (north and south). Assuming a level straight approach, the vehicles need only be weighed in one direction to save time in obtaining the data that represent the whole population. On other hand, the sample for each of the vehicles does not represent the entire population. This problem implies that the conclusions and recommendations that can be made using these samples were not reliable. The samples reliability were needed to estimate the number of tests that were required to determine if the portable static scales were capable of weighing multiaxle vehicles to an accuracy of ±1 percent of the gross vehicle weight.

Some decisions need to be made using samples of a particular population. The results of the sampling experiment are used to predict the consequences of making specific engineering decisions for the total population. It is important that the sample be random and be the correct size because it will be used as a representation of the entire population.

When the collection of data is needed for the study or to analyze the characteristics of a group of objects, people, etc., it is sometime impossible or impractical to observe the entire group, specifically if this group is large. Instead of gathering all the group (population), some samples that describe the entire population can be obtained. Important conclusions about the population can often be inferred from analyzing the sample, if the sample is representative of a population. Samples that can be gathered in the field are of two sizes: small ($n < 30$) and large ($n \geq 30$). It important to know that with large samples a greater precision in the results can be gathered, but it implies a lot of investment in time and money. A good balance between the confidence level and the investment needs to be found. The purpose of this appendix is to discuss the importance of sample size and how to secure it in the field according to the purpose of the research.

A.2 SMALL SAMPLES.

The collection of small samples is more economical because the time and the human and non-human resources that were used to gather it is less than the time needed to gather a large sample. The statistic used for small samples are based on two distributions, the t and the chi-square and the results that it provides are more accurate. The *t*

distribution's curve is symmetrical or bell-shaped and very similar to the normal curve. Also, the statistics inference that we can make about it are very similar to the normal distribution inference. With these distributions we can define 95 percent, 99 percent or other confidence limits and intervals using the table distribution that appears in some statistics books (Walpole 1972 and Montgomery 1980). These tables are defined for $n \leq 30$, in other cases, use the normal tables. The first equation is for the confidence limits for population means using the t distribution. Using this equation, the specific confidence level and the accuracy that is desired in the results can be obtained.

$$\overline{X} \pm t_c \frac{s}{\sqrt{(N-1)}} \qquad \textbf{(A.1)}$$

where

X = means
t_c = critical value or confidence coefficient
s = standard deviation
N = sample size

The critical value (t_c) depends on the level of confidence desired and the sample size it can be obtained from tables.

Another distribution used for the analysis of the small samples is the chi-square distribution. The curve for this distribution is skewed to the right or has a positive skew, but when the sample size increases the shape of the curve become more symmetrical. As with the t distribution, we can define 95 percent, 99 percent or other confidence limits and intervals for chi-square by the use of the chi-square distribution tables. With this method, the population standard deviation (σ) in terms of a sample standard deviation (s) can be estimated. Equation A-2 shows the confidence interval for the confidence level and accuracy desired in the standard deviation.

$$\frac{s\sqrt{N}}{X_{1-\alpha}} < \sigma < \frac{s\sqrt{N}}{X_{\alpha}} \qquad \textbf{(A.2)}$$

where

σ = standard deviation of the population
s = standard deviation of the sample
N = sample size
X = critical value for chi-square distribution
α = error type 1

A.3 LARGE SAMPLES.

Large samples use normal distribution for statistic inference. The size of the sample needs to be known to ensure that the error in estimating μ will be less than the specified amount of an error (e). See the next illustration.

$$\overline{X} - Z_{\frac{\alpha}{2}} \frac{\sigma}{\sqrt{n}} \quad \longleftarrow \text{Error (e)} \longrightarrow \quad \overline{X} + Z_{\frac{\alpha}{2}} \frac{\sigma}{\sqrt{n}}$$

Two theorems exist to solve this problem which includes the confidence level and the accuracy wanted in the results. The theorems were obtained from probability and statistic books (Walpole 1972 and Montgomery 1980).

Theorem 1. If x is used as an estimate of μ, we can be $(1-\alpha)100$ percent confident that the error will be less than $Z_{\frac{\alpha}{2}} \frac{\sigma}{\sqrt{n}}$.

Theorem 2. If x is used as an estimate of μ, we can be $(1-\alpha)100$ percent confident that the error will be less than a specified amount e when the sample size is,

$$n = \left[\frac{Z_{\frac{\alpha}{2}}\ \sigma}{e} \right]^2 \qquad \textbf{(A.3)}$$

The formula in the second theorem is only applicable if the variance of the population from the sample is known. The preliminary sample size of $n \geq 30$ could be used to provide an estimate of σ and then can use the previous equation to find the number of observations that are needed to provide the desired degree of accuracy and confidence level.

A.4 PROBLEM TO SOLVE.

The correct amount of running with and without leveling boards that can be collected in the field to get a 95 percent confidence level and 3 percent, 2 percent and 1 percent accuracy in our results need to be estimated. The literature review shows the need to obtain a preliminary sample ($n \geq 30$) to get the variance and then calculate the number of running. In addition, if the direction (north and south) in the data collection has an important implication.

A.5 PRELIMINARY CONCLUSION.

The sample size that can be calculated using a 95 percent of accuracy, $\alpha = 0.05$ and the estimated variance. The assumption that the mean of the sample is equal to the mean of the population is not true. The use of the analysis of variance can help us to determine if the direction in which the data were gathered has a significant difference. We use the statistical inference to prove if the means and variance between the south and north direction were different. In conclusion, we obtain that the means between the south sample and the north sample are equal. Also, the statistical inference proves the variance between the direction are equal. The results were obtained for a 95 percent of confidence level and $\alpha = 0.05$.

TESTING IF THE MEANS OF NORTH AND SOUTH DIRECTION ARE SIGNIFICANTLY DIFFERENT

DATE	VEH	DIR	BOARDS	SCALE	WEIGHT	R1	R2	R3	R4	R5	R6	R7	R8
05/21/92	GMC	S		SAS	48320	49520	49480	49240	49540	49440	50368	49320	49220
05/21/92	GMC	N		SAS	48320	49140	49040	48980	49020	48940	49500	47240	49260
05/22/92	GMC	S		PAT	48320	55440	55440	54980	55440	55680			
05/22/92	GMC	N		PAT	48320	54880	55360	55500	54380	54820			
05/22/92	GMC	S	WB	PAT	80700	82220	81940	81960	81960	80520	88860	89100	88260
05/22/92	GMC	N	WB	PAT	80700	81280	81540	80820	81260	81540	87520	83400	88580
05/22/92	BLUE T	S	WB	PAT	69070	70240	69420	69880	69320	69540	71800	71740	70820
05/22/92	BLUE T	N	WB	PAT	69070	69320	68960	69620	69680	70200	70080	71340	70580
05/21/92	TRACT	S	WB	PAT	36630	37200	37140	37120	37460	37600	37660	36980	36860
05/21/92	TRACT	N	WB	PAT	36630	36740	37300	37300	37020	36720	37320	38540	37640

DATE	VEH	DIR	BOARDS	SCALE	WEIGHT	R9	R10	R11	R12	R13	R14	R15
05/21/92	GMC	S		SAS	48320	49620	48560					
05/21/92	GMC	N		SAS	48320	49500	49860					
05/22/92	GMC	S		PAT	48320							
05/22/92	GMC	N		PAT	48320							
05/22/92	GMC	S	WB	PAT	80700	87160	86040					
05/22/92	GMC	N	WB	PAT	80700	88820	88340					
05/22/92	BLUE T	S	WB	PAT	69070	71100	71240					
05/22/92	BLUE T	N	WB	PAT	69070	71980	71700					
05/21/92	TRACT	S	WB	PAT	36630	37360	38080	38480	38640	39080	37920	38560
05/21/92	TRACT	N	WB	PAT	36630	36860	36540	38140	39200	39140	38180	38240

Ho: The mean of the south and north direction are equal

Ho: The mean of the south and north direction are not equal

alpha= 0.05

C. I.= 0.95

DIFFERENCE BETWEEN SOUTH AND NORTH

di	380	440	260	520	500	868	2080	-40	120	-1300			
	560	80	-520	1060	860								
	940	400	1140	700	-1020	1340	5700	-320	-1660	-2300			
	920	460	260	-360	-660	1720	400	240	-880	-460			
	460	-160	-180	440	880	340	-1560	-780	500	1540	340	-560	-60
												-260	320

di(mean)	di(std	n	DF	t	Tcrit1	Tcrit2	Conclusion
382.8	833.1	10	9	1.453	-2.262	2.262	The two directions are not significatly different
408	636.6	5	4	1.433	-2.776	2.776	The two directions are not significatly different
492	2208	10	9	0.705	-2.262	2.262	The two directions are not significatly different
164	787.7	10	9	0.658	-2.262	2.262	The two directions are not significatly different
92.30769	782	15	14	0.457	-2.145	2.145	The two directions are not significatly different

Scale:Single axle
date: 5-21-92
Vehicle: 4 axles-GMC
Total Weight West 48300 Total Weight East: 48340 Average 48320

Direction: south

Axles	Run 1	2	3	4	5	Mean	Stand	Var	Cov
1	16140	16160	16100	16180	16140	16144	29.665	880	0.184
2	13760	13700	13640	13720	13660	13696	47.749	2280	0.349
3	11840	11840	11720	11780	11760	11788	52.154	2720	0.442
4	7780	7780	7780	7860	7880	7816	49.800	2480	0.637
Total	49520	49480	49240	49540	49440	49444	120.333	14480	0.243
Error	2.4233	2.3444	1.8684	2.4627	2.2654	2.2733			

Direction: north

Axles	Run 1	2	3	4	5	Mean	Stand	Var	Cov
1	15540	15460	15500	15480	15500	15496	29.665	880	0.191
2	14060	14060	14020	14080	14020	14048	26.833	720	0.191
3	10960	10980	10920	10920	10900	10936	32.863	1080	0.301
4	8580	8540	8540	8540	8520	8544	21.909	480	0.256
Total	49140	49040	48980	49020	48940	49024	75.366	5680	0.154
Error	1.6687	1.4682	1.3475	1.428	1.2669	1.436			
Dif. between North and South	0.7546	0.8153	0.7177	0.797	0.8372				

Scale:PAT
date: 5-22-92
Vehicle: 4 axles-GMC
Total Weight West 48300 Total Weight East: 48340 Average 48320

Direction: south

Axles	Run 1	2	3	4	5	Mean	Stand	Var	Cov
1	17120	17040	17160	17320	17220	17172	105.451	11120	0.614
2	14940	15060	15080	14940	15100	15024	77.974	6080	0.519
3	13720	13640	13540	13540	13640	13616	76.681	5880	0.563
4	9660	9700	9200	9640	9720	9584	216.979	47080	2.264
Total	55440	55440	54980	55440	55680	55396	254.716	64880	0.46
Error	12.843	12.843	12.113	12.843	13.218	12.773			

Direction: north

Axles	Run 1	2	3	4	5	Mean	Stand	Var	Cov
1	16620	16560	16640	16280	16380	16496	158.367	25080	0.96
2	14860	15260	15160	14740	15100	15024	216.518	46880	1.441
3	12940	13020	13060	12940	12920	12976	60.663	3680	0.468
4	10460	10520	10640	10420	10420	10492	92.304	8520	0.88
Total	54880	55360	55500	54380	54820	54988	450.022	202520	0.818
Error	11.953	12.717	12.937	11.144	11.857	12.126			
Dif. between North and South	0.889	0.126	0.823	1.699	1.361				

Scale:PAT without boards
date: 5-22-92
Vehicle: 4 axles-GMC
Total Weight West 80680 Total Weight East: 80720 Average 80700

Direction: south

Axles	Run 1	2	3	4	5	Mean	Stand	Var	Cov
1	20000	19980	20080	20000	19980	20008	41.473	1720	0.207
2	19380	19320	19420	19240	19360	19344	68.411	4680	0.354
3	22860	22960	23080	22780	21240	22584	759.658	577080	3.364
4	19980	19680	19380	19940	19940	19784	255.500	65280	1.291
Total	82220	81940	81960	81960	80520	81720	680.735	463400	0.833
Error	1.8487	1.5133	1.5373	1.5373	0.2235	1.2482			

Direction: north

Axles	Run 1	2	3	4	5	Mean	Stand	Var	Cov
1	18620	19060	19180	19060	19060	18996	216.518	46880	1.14
2	19620	19460	19160	19680	19520	19488	202.287	40920	1.038
3	22040	22020	21740	21780	22020	21920	146.969	21600	0.67
4	21000	21000	20740	20740	20940	20884	133.716	17880	0.64
Total	81280	81540	80820	81260	81540	81288	294.483	86720	0.362
Error	0.0071	0.0103	0.0015	0.0069	0.0103	0.0072			

Dif. between North and South
1.8416 1.6726 1.627 1.6029 1.2409

Scale:PAT without boards
date: 5-22-92
Vehicle: 4 axles-GMC
Total Weight West 80680 Total Weight East: 80720 Average 80700

Direction: south

Axles	Run 1	2	3	4	5	Mean	Stand	Var	Cov
1	20500	20500	20380	20200	20300	20376	129.923	16880	0.638
2	21220	21220	21120	20800	21020	21076	175.157	30680	0.831
3	23860	24220	23740	23800	23120	23748	397.643	158120	1.674
4	23280	23160	23020	22360	21600	22684	702.624	493680	3.097
Total	88860	89100	88260	87160	86040	87884	1274.472	1.6E+06	1.45
Error	9.183	9.4276	8.5656	7.4117	6.2064	8.1744			

Direction: north

Axles	Run 1	2	3	4	5	Mean	Stand	Var	Cov
1	20780	21060	21240	21320	21240	21128	216.610	46920	1.025
2	20780	20060	20740	20680	20620	20576	294.754	86880	1.433
3	20340	22060	25060	25040	24520	24204	1239.63	2E+06	5.122
4	21620	20220	21540	21780	21960	21424	692.01	478880	3.230
Total	87520	83400	88580	88820	88340	87332	2251.87	5E+06	2.579
Error	7.793	3.237	8.896	9.142	8.648	7.594			

Dif. between North and South
1.39 6.19 0.33 1.73 2.44

Scale:PAT without boards
date: 5-21-92
Vehicle: Blue Trucks
Total Weight West 69020 Total Weight East: 69120 Average 69070

Direction: south

Axles	Run 1	2	3	4	5	Mean	Stand	Var	Cov
1	9640	9440	9500	9360	9400	9468	109.179	11920	1.153
2	14380	13800	14060	13920	14120	14056	219.727	48280	1.563
3	13800	13820	13780	13780	13640	13764	71.274	5080	0.518
4	16460	16200	16400	16280	16320	16332	101.587	10320	0.622
5	15960	16160	16140	15980	16060	16060	90.554	8200	0.564
Total	70240	69420	69880	69320	69540	69680	377.624	142600	0.542
Error	1.6657	0.5042	1.1591	0.3606	0.6759	0.8754			

Direction: north

Axles	Run 1	2	3	4	5	Mean	Stand	Var	Cov
1	9220	9600	9160	9260	9160	9280	183.848	33800	1.981
2	14060	13420	14280	13900	14420	14016	388.433	150880	2.771
3	13800	13980	14020	14180	14120	14020	146.287	21400	1.043
4	16280	16340	16340	16300	16300	16312	26.833	720	0.164
5	15960	15620	15820	16040	16200	15928	220.273	48520	1.383
Total	69320	68960	69620	69680	70200	69556	459.652	211280	0.661
Error	0.3606	0.1595	0.79	0.8754	1.6097	0.6987			

Dif. between North and South

1.3051	0.9871	0.7801	0.4569	0.1767

Scale:PAT without boards
date: 5-22-92
Vehicle: Blue Trucks
Total Weight West 69020 Total Weight East: 69120 Average 69070

Direction: south

Axles	Run 1	2	3	4	5	Mean	Stand	Var	Cov
1	9560	9380	9340	9520	9660	9492	131.605	17320	1.386
2	14540	14540	14120	13940	14080	14244	278.352	77480	1.954
3	14240	14260	14160	14280	14400	14268	86.718	7520	0.608
4	16740	16780	16780	16640	16640	16716	71.274	5080	0.426
5	16720	16780	16420	16720	16460	16620	166.733	27800	1.003
Total	71800	71740	70820	71100	71240	71340	421.189	177400	0.59
Error	3.8022	3.7218	2.4711	2.8551	3.046	3.1819			

Direction: north

Axles	Run 1	2	3	4	5	Mean	Stand	Var	Cov
1	8820	9780	8940	9420	9740	9340	444.522	197600	4.759
2	14340	14540	14680	15000	14060	14524	353.667	125080	2.435
3	13860	13740	13920	14560	14500	14116	384.031	147480	2.721
4	16440	16460	16520	16460	16520	16480	37.417	1400	0.227
5	16620	16820	16520	16540	16880	16676	164.560	27080	0.987
Total	70080	71340	70580	71980	71700	71136	789.987	624080	1.111
Error	1.4412	3.1819	2.1394	4.0428	3.6681	2.9043			

Dif. between North and South

2.361	0.540	0.332	1.188	0.622

Scale:PAT without boards
date: 5-21-92
Vehicle: Blue Tractor lowboy
Total Weight West 36600   Total Weight East: 36660   Average 36630

Direction: south Run

Axles	1	2	3	4	5	Mean	Stand	Var	Cov
1	9860	9720	9740	9700	9720	9748	64.187	4120	0.658
2	7740	7820	7940	7860	8140	7900	152.315	23200	1.928
3	7180	7140	7320	7400	7260	7260	104.881	11000	1.445
4	6260	6280	6120	6260	6280	6240	67.823	4600	1.087
5	6160	6180	6000	6240	6200	6156	92.087	8480	1.496
Total	37200	37140	37120	37460	37600	37304	214.196	45880	0.574
Error	0.0153	0.0137	0.0132	0.0222	0.0258	0.0181			

Direction: north Run

Axles	1	2	3	4	5	Mean	Stand	Var	Cov
1	9640	9720	9640	9560	9620	9636	57.271	3280	0.594
2	7320	7860	7740	7540	7280	7548	254.008	64520	3.365
3	7360	7300	7300	7400	7200	7312	75.631	5720	1.034
4	6160	6100	6280	6200	6280	6204	77.974	6080	1.257
5	6260	6320	6340	6320	6340	6316	32.863	1080	0.52
Total	36740	37300	37300	37020	36720	37016	285.096	81280	0.77
Error	0.2994	1.7962	1.7962	1.0535	0.2451	1.0428			

Dif. between North and South

1.2329	0.3993	0.1063	0.3714	0.764

Scale:PAT without boards
date: 5-22-92
Vehicle: Blue Tractor lowboy
Total Weight West 36600   Total Weight East: 36660   Average 36630

Direction: south
Right: Front Run

Wheel	1	2	3	4	5	Mean	Stand	Var	Cov
1	4920	4660	4940	5000	5120	4928	168.879	28520	3.427
2	3800	4260	3720	3680	3900	3872	232.637	54120	6.008
3	3640	3420	3460	3580	3700	3560	118.322	14000	3.324
4	3100	2900	2980	2860	2860	2940	101.980	10400	3.469
5	3440	3280	3260	3260	3200	3288	90.111	8120	2.741
Total	18900	18520	18360	18380	18780	18588	241.909	58520	1.301

Left: Front Run

Wheel	1	2	3	4	5	Mean	Stand	Var	Cov
1	5100	4960	5000	5200	5180	5088	106.395	11320	2.091
2	3960	3620	3560	3800	3980	3784	191.520	36680	5.061
3	3500	3680	3560	3780	3680	3640	110.454	12200	3.034
4	3220	3260	3440	3220	3420	3312	109.179	11920	3.296
5	2980	2940	2940	2980	3040	2976	40.988	1680	1.377
Total	18760	18460	18500	18980	19300	18800	349.857	122400	1.861
Total weight	37660	36980	36860	37360	38080	37388			
Error	2.735	0.9465	0.624	1.954	3.8078	2.0274			

Direction: north

Left: Front

Wheel	Run 1	2	3	4	5	Mean	Stand	Var	Cov
1	5060	4860	4960	4860	4860	4920	89.443	8000	1.818
2	3840	3800	3560	3980	3640	3764	166.373	27680	4.42
3	4040	3840	3640	3820	3780	3824	143.805	20680	3.761
4	3180	3160	3000	2880	2920	3028	136.821	18720	4.519
5	2920	4140	3020	2960	2980	3204	524.481	275080	16.37
Total	19040	19800	18180	18500	18180	18740	688.912	474600	3.676

Right: Front

Wheel	Run 1	2	3	4	5	Mean	Stand	Var	Cov
1	4980	4840	4980	4860	4860	4904	69.857	4880	1.424
2	3300	3580	3660	3520	3520	3516	133.716	17880	3.803
3	3540	3700	3700	3440	3440	3564	130.690	17080	3.667
4	3160	3100	3600	3020	3020	3180	242.074	58600	7.612
5	3300	3520	3520	3520	3520	3476	98.387	9680	2.83
Total	18280	18740	19460	18360	18360	18640	492.138	242200	2.64
Total weight	37320	38540	37640	36860	36540	37380			
Error	1.8489	4.9559	2.6833	0.624	0.2463	2.0064			

Dif. between North and South

0.8861 1.5785 1.7367 0.9819 -0.021

Scale:PAT without boards
date: 5-22-92
Vehicle: Blue Tractor lowboy
Total Weight West 36600 Total Weight East: 36660 Average 36630

Direction: south

Wheel	Run 1	2	3	4	5	Mean	Stand	Var	Cov
1	9820	9800	9820	9760	9760	9792	30.332	920	0.31
2	7720	7920	7940	7580	7920	7816	159.625	25480	2.042
3	7720	7600	8080	7440	7800	7728	238.998	57120	3.093
4	6660	6500	6640	6500	6520	6564	79.246	6280	1.207
5	6560	6820	6600	6640	6560	6636	108.074	11680	1.629
Total	38480	38640	39080	37920	38560	38536	415.307	172480	1.078
Error	4.8077	5.2019	6.2692	3.4019	5.0052	4.946			

Direction: north

Wheel	Run 1	2	3	4	5	Mean	Stand	Var	Cov
1	9740	10360	9800	9840	9620	9872	285.167	81320	2.889
2	7780	7920	8260	7720	7940	7924	209.476	43880	2.644
3	7880	7720	7760	7600	7560	7704	128.374	16480	1.666
4	6240	6420	6480	6380	6600	6424	132.212	17480	2.058
5	6500	6780	6840	6640	6520	6656	151.921	23080	2.282
Total	38140	39200	39140	38180	38240	38580	540.185	291800	1.4
Error	3.9591	6.5561	6.4129	4.0597	4.2103	5.0544			

Dif. between North-South

0.8486 1.354 0.144 0.658 0.795

Scale:Single axle
date: 5-22-92
Vehicle: 4 axles-GMC
Total Weight West 48300 Total Weight East: 48340 Average 48320

Direction: south

Right: Front Wheel	Run 1	2	3	4	5	Mean	Stand	Var	Cov
1	7940	7920	7900	7880	7960	7920	31.623	1000	0.399
2	6960	7040	7000	7020	6940	6992	41.473	1720	0.593
3	6268	5920	5960	6060	5860	6013.6	159.765	25525	2.657
4	4180	3980	3920	4040	3700	3964	176.295	31080	4.447
Total	25348	24860	24780	25000	24460	24890	323.946	104941	1.302

Left: Front Wheel	Run								
1	7920	7900	7920	7920	7760	7884	69.857	4880	0.886
2	6820	6820	6820	6840	6700	6800	56.569	3200	0.832
3	6240	5900	5880	5980	5880	5976	153.232	23480	2.564
4	4040	3840	3820	3880	3760	3868	105.451	11120	2.726
Total	25020	24460	24440	24620	24100	24528	333.946	111520	1.361
Total weight	50368	49320	49220	49620	48560	49418			
Error	4.0661	2.0276	1.8285	2.6199	0.4942	2.2211			

Direction: north

Right: Front Wheel	Run 1	2	3	4	5	Mean	Stand	Var	Cov
1	7880	7840	7840	7500	7860	7784	159.625	25480	2.051
2	7200	7180	6980	7100	7220	7136	98.387	9680	1.379
3	5680	6140	5680	5740	5440	5736	253.535	64280	4.42
4	4580	4500	4560	4800	4480	4584	127.593	16280	2.783
Total	25340	25660	25060	25140	25000	25240	267.582	71600	1.06

Left: Front Wheel	Run 1	2	3	4	5	Mean	Stand	Var	Cov
1	7420	4420	7460	7440	7560	6860	1365.064	1.9E+06	19.9
2	6840	6880	6860	6860	7240	6936	170.529	29080	2.459
3	5640	6040	5680	5640	5780	5756	168.760	28480	2.932
4	4260	4240	4200	4420	4280	4280	83.666	7000	1.955
Total	24160	21580	24200	24360	24860	23832	1289.387	1.7E+06	5.41
Total weight	49500	47240	49260	49500	49860	49072			
Error	2.3838	2.2862	1.9082	2.3838	3.0886	1.5324			

Dif. between North-South

1.6822	0.259	0.080	0.236	2.594

DATE	VEH	DIR	BOARDS	SCALE	WEIGHT	R1	R2	R3	R4	R5	MEAN	STD. DEV.
05/21/92	GMC	S		SAS	48320	49520	49480	49240	49540	49440	49444	120.33
05/21/92	GMC	N		SAS	48320	49140	49040	48980	49020	48940	49024	75.37
05/22/92	GMC	S		SAS	48320	50368	49320	49220	49620	48560	49418	657.32
05/22/92	GMC	N		SAS	48320	49500	47240	49260	49500	49860	49072	1046.29
05/22/92	GMC	S		PAT	48320	55440	55440	54980	55440	55680	55396	254.72
05/22/92	GMC	N		PAT	48320	54880	55360	55500	54380	54820	54988	450.02
05/22/92	GMC	S	WB	PAT	80700	82220	81940	81960	81960	80520	81720	680.73
05/22/92	GMC	N	WB	PAT	80700	81280	81540	80820	81260	81540	81288	294.48
05/22/92	GMC	S	WB	PAT	80700	88860	89100	88260	87160	86040	87884	1274.47
05/22/92	GMC	N	WB	PAT	80700	87520	83400	88580	88820	88340	87332	2251.87
05/22/92	BLUE T	S	WB	PAT	69070	70240	69420	69880	69320	69540	69680	377.62
05/22/92	BLUE T	N	WB	PAT	69070	69320	68960	69620	69680	70200	69556	459.65
05/22/92	BLUE T	S	WB	PAT	69070	71800	71740	70820	71100	71240	71340	421.19
05/22/92	BLUE T	N	WB	PAT	69070	70080	71340	70580	71980	71700	71136	789.99
05/21/92	TRACT	S	WB	PAT	36630	37200	37140	37120	37460	37600	37304	214.20
05/21/92	TRACT	N	WB	PAT	36630	36740	37300	37300	37020	36720	37016	285.10
05/22/92	TRACT	S	WB	PAT	36630	37660	36980	36860	37360	38080	37388	499.72
05/22/92	TRACT	N	WB	PAT	36630	37320	38540	37640	36860	36540	37380	773.43
05/22/92	TRACT	S	WB	PAT	36630	38480	38640	39080	37920	38560	38536	415.31
05/22/92	TRACT	N	WB	PAT	36630	38140	39200	39140	38180	38240	38580	540.19

Data by direction

DATE	VEH	DIR	BOARDS	SCALE	WEIGHT	R1	R2	R3	R4	R5	MEAN	STD. DEV.
05/21/92	GMC	S		SAS	48320	49520	49480	49240	49540	49440	49444	
05/22/92	GMC	S		SAS	48320	50368	49320	49220	49620	48560	49417.6	445.71
05/21/92	GMC	N		SAS	48320	49140	49040	48980	49020	48940	49024	
05/22/92	GMC	N		SAS	48320	49500	47240	49260	49500	49860	49072	699.79
05/22/92	GMC	S		PAT	48320	55440	55440	54980	55440	55680	55396	254.72
05/22/92	GMC	N		PAT	48320	54880	55360	55500	54380	54820	54988	450.02
05/22/92	GMC	S	WB	PAT	80700	82220	81940	81960	81960	80520	81720	
05/22/92	GMC	S	WB	PAT	80700	88860	89100	88260	87160	86040	87884	3388.51
05/22/92	GMC	N	WB	PAT	80700	81280	81540	80820	81260	81540	81288	
05/22/92	GMC	N	WB	PAT	80700	87520	83400	88580	88820	88340	87332	3526.97
05/22/92	BLUE T	S	WB	PAT	69070	70240	69420	69880	69320	69540	69680	
05/22/92	BLUE T	S	WB	PAT	69070	71800	71740	70820	71100	71240	71340	952.72
05/22/92	BLUE T	N	WB	PAT	69070	69320	68960	69620	69680	70200	69556	
05/22/92	BLUE T	N	WB	PAT	69070	70080	71340	70580	71980	71700	71136	1031.85
05/21/92	TRACT	S	WB	PAT	36630	37200	37140	37120	37460	37600	37304	
05/22/92	TRACT	S	WB	PAT	36630	37660	36980	36860	37360	38080	37388	
05/22/92	TRACT	S	WB	PAT	36630	38480	38640	39080	37920	38560	38536	687.14
05/21/92	TRACT	N	WB	PAT	36630	36740	37300	37300	37020	36720	37016	
05/22/92	TRACT	N	WB	PAT	36630	37320	38540	37640	36860	36540	37380	
05/22/92	TRACT	N	WB	PAT	36630	38140	39200	39140	38180	38240	38580	869.43

TEST #1
Ho: the variance of the two population are equal
H1: the variance are not equal

Group #1
Pooled variance

Sp^2 =	3E+05	2E+05
q =	0.77	5E+05
h =	1.056	7E+05
b =	1.679	0.711
alpha =	0.05	
nu =	1	
B =	3.841	page 461

b < B, then
Conclusion: The variance of the two population are equal

Group #2
Pooled variance

Sp^2 =	133700	
q =	0.5347	
h =	1.125	
b =	1.0945	
alpha =	0.05	
nu =	1	
B =	3.841	page 461

b < B, then
Conclusion: The variances are equal

Group #3
Pooled variance

Sp^2 =	1E+07	
q =	0.006	
h =	1.056	
b =	0.014	
alpha =	0.05	
nu =	1	
B =	3.841	page 461

b < B, then
Conclusion: The variance of the two population are equal

Group #4
Pooled variance

Sp^2 =	986191	
q =	0.0249	
h =	1.0556	
b =	0.0542	
alpha =	0.05	
nu =	1	
B =	3.841	page 461

b < B, then
Conclusion: The variances are equal

Group #5
Pooled variance

Sp^2 =	7E+06	
q =	29.91	
h =	1.036	
b =	66.49	
alpha =	0.05	
nu =	1	
B =	3.841	page 461

b < B, then Conclusion: The variance of the two population are equal

TEST #2

Ho: The samples means are equal

H1: at least two of the means are not equal

alpha=	0.05		
nu1 =	1	1	1
nu2 =	9	4	14
F	5.12	7.7	4.6

Anova: Group 1

Source of variation	Sum of Squares	Degree of freedom	Mean Square	Computed f
Treatments	7E+05	1	732679	2.1287
Error	6E+06	18	344183	
Total	7E+06	19		

Conclusion: f < F the sample have equal mean

Anova: Group 2

Source of variation	Sum of Squares	Degree of freedom	Mean Square	Computed f
Treatments	4E+05	1	416160	3.1126
Error	1E+06	8	133700	
Total	1E+06	9		

Conclusion: f < F the sample have equal mean

Anova: Group 3

Source of variation	Sum of Squares	Degree of freedom	Mean Square	Computed f
Treatments	1E+06	1	1E+06	0.1012
Error	2E+08	18	1E+07	
Total	2E+08	19		

Conclusion: f < F the sample have equal mean

Anova: Group 4

Source of variation	Sum of Squares	Degree of freedom	Mean Square	Computed f
Treatments	1E+05	1	134480	0.1364
Error	2E+07	18	986191	
Total	2E+07	19		

Conclusion: f < F the sample have equal mean

Anova: Group 1

Source of variation	Sum of Squares	Degree of freedom	Mean Square	Computed f
Treatments	52920	1	52920	0.0862
Error	2E+07	28	614038	
Total	2E+07	29		

Conclusion: f < F the sample have equal mean

TEST #3

Checking if exist any different between SSA and PAT

Pooled variance

Sp^2 =	7E+06	
q =	39	
h =	1.043	
b =	86.12	
alpha =	0.05	
nu =	1	
B =	3.841	page 461

b > B, then

Conclusion: The variance of the two scales are not equal

TEST #4

A 95% confidence intervals for the mean

alpha = 0.05

Group	mean	n	nu	s	t	Confidence interval		
1	49239	20	19	603.8	2.093	48957	<Mean<	49522
2	55192	10	9	406.3	2.262	54901	<Mean<	55483
3	84556	20	19	3376	2.093	82976	<Mean<	86136
4	70428	20	19	970.2	2.093	69974	<Mean<	70882
5	37701	30	29	771.2	2.045	37413	<Mean<	37989

A 95% confidence intervals for the variance of a normal population

Group	n	n-1	s^2	X0.025	X0.975	Confidence interval		
1	20	19	4E+05	32.85	8.907	210884	< V^2 <	777813
2	10	9	2E+05	19.02	2.7	78103	< V^2 <	550281
3	20	19	1E+07	32.85	8.907	7E+06	< V^2 <	2E+07
4	20	19	9E+05	32.85	8.907	544439	< V^2 <	2E+06
5	30	29	6E+05	45.72	16.047	377192	< V^2 <	1E+06

TEST #5: Cochran's test

1. Ho: the variance of the two population are equal
2. H1: the variance are not equal
3. alpha = 0.05
4. Critical Region: G find in table XI, page 473

5. Computations:

Group	alpha	n	S (l)^	S (u)^	S total	g	G	Conclusion
1	0.05	10	2E+05	5E+05	688366	0.7114	0.801	Equal variance between north and south dir.
2	0.05	5	64880	2E+05	267400	0.7574	0.9057	Equal variance between north and south dir.
3	0.05	10	1E+07	1E+07	2E+07	0.52	0.801	Equal variance between north and south dir.
4	0.05	10	9E+05	1E+06	2E+06	0.5398	0.801	Equal variance between north and south dir.
5	0.05	15	5E+05	8E+05	1E+06	0.6155	0.7521	Equal variance between north and south dir.

APPENDIX B

EXAMPLE OF THE FORM USED TO WRITE THE DATA

This form is an example of the data sheet used to write the weight measurements and other information for the 3-axle vehicles, GMC truck.

P.A.T. SCALE DATA

DATE: ____________
TIME: ____________
TEMP: ____________
CONDITION: ____________

VEHICLE: ____________
AXLES: ____________
BLOCKS: ____________
DRIVER: ____________
TIRE PRESSURE: ____________

	AXLES		
RUN	1	2	3
1			
2			
3			
4			
5			
6			
7			
8			
9			
10			
11			
12			
13			
14			
15			
16			
17			
18			
19			
20			
21			
22			
23			
24			
25			
26			
27			
28			
29			
30			
NOTES:			

APPENDIX C

PAT SAMPLES PARAMETERS

C.1 INTRODUCTION.

All the information from the field test is summarized in this appendix. The data display is similar to the data form used in the field (see Appendix B). The information includes date, time, temperature, weather condition, vehicle type, number of axles, type of block used for loading the vehicle (lead or steel), amount of load, driver weight, and tire pressure. The Mississippi scale data are the EAST and WEST weight entries, and the total gross weight used is the average between both (average weight). For each vehicle the mean, standard deviation, covariance, percent of error, maximum, and minimum were calculated. The sample mean and variance were compared with the evaluated using the test of hypothesis. Cochran's test was used to compare the variance between the loaded and unloaded condition. The ANOVA test compared the mean between both loaded and unloaded samples.

C.2 DEFINITIONS.

Some equations and definitions used in the text and calculations are shown below:

Sample mean (μ_s) - a value which is typical or representative of a set of data. This typical value is known as the measure of central tendency because it tends to lie centrally within a set of data arranged according to magnitude.

$$\mu_s = \frac{X_1+X_2+X_3+...+X_j}{n} \qquad (C.1)$$

where
X_j = weight observed on the scale, j = 1 to n
n = total number of observations

Population mean (μ) - a value which is typical or representative of the entire population. This typical value is known as the measure of central tendency because it tends to lie centrally within the population arranged according to magnitude.

$$\mu = \frac{X_1+X_2+X_3+...+X_j}{n=\infty} \qquad (C.2)$$

where
X_j = weight observed in the scale, j = 1 to n
n = total number of observations

Variation or dispersion - the degree by which the numerical data tends to spread about the mean.

Dispersion (d) - the difference between what has been expected or predetermined and what actually occurs.

$$d = X_j - \mu_s \qquad \text{(C.3)}$$

where
- X_j = weight observed in the scale
- μ_s = sample mean weight

Sample standard deviation (s) - measure of dispersion or variation for a sample drawn from a specific population.

$$s = \sqrt{\frac{\Sigma(X_j - \mu_s)^2}{n-1}} = \sqrt{\frac{\Sigma(d)^2}{n-1}} \qquad \text{(C.4)}$$

where
- d = deviation
- n = total number of observations

Population standard deviation (σ)- measure of dispersion or variation for a specific population.

$$\sigma = \sqrt{\frac{\Sigma(X_j - \mu_s)^2}{n}} = \sqrt{\frac{\Sigma(d)^2}{n}} \qquad \text{(C.5)}$$

Sample variance (s^2) - the square of the sample's standard deviation, which is the mean square of the deviation from the sample mean.

$$s^2 = \frac{\Sigma(X_j - \mu_s)^2}{n-1} = \frac{\Sigma(d)^2}{n-1} \qquad \text{(C.6)}$$

Population variance (σ^2) - the square of the population's standard deviation, which is the mean square of the deviation from the population mean.

$$\sigma^2 = \frac{\Sigma(X_j - \mu_s)^2}{n} = \frac{\Sigma(d)^2}{n} \qquad \text{(C.7)}$$

Range - the difference between the largest and smallest number in the set. It could be indicated as A to B, or simply A-B.

Error (e) - the difference between what has been expected or predetermined and what actually occurs divided by the expected. If percent of error is desired then multiply by 100.

$$e = \frac{(\mu - \mu_s)}{\mu} \qquad \text{(C.8)}$$

C.3 TEST OF HYPOTHESIS.

The test of hypothesis is an assertion or conjecture concerning one or more populations. Sample parameters such as variance, mean, and correlation coefficients are tested to determine the validity associated with using the values to make inference about the population.

Part of this procedure is specifying the set of values for the statistics test (t or z) which leads to rejection of H_o. This set of values is called the critical region or rejection region for the test. The rejection region implies that a sample can be used to make inferences about population parameters, distributions, and other characteristics that describe the population.

The test of hypotheses is described as:

1. Null hypothesis, H_o: $\mu_s = \mu$
2. Alternative hypothesis, H_a: $\mu_s \neq \mu$
3. Statistics test such t or z
4. Rejection region
5. Conclusion

The following pages show the vehicle weight using the PAT and Mississippi scales. Also, the result for each sample parameter and the test of hypothesis to compare the samples and the population. The first test of hypothesis evaluate the sample mean with the population mean. The second compares the sample and population variance using Cochran's test. The last test, ANOVA, compares the sample mean to the load conditions.

P.A.T. SCALE DATA: GMC/ARMY TRUCK (Load)

DATE: 06/23/92
TIME: 01:05 PM
TEMP (F): 101
CONDITION: SUNNY & HUMID

M.S. EAST WGHT: 80920 lb
M.S. WEST WGHT: 80860 lb

VEHICLE: GMC/ARMY TRUCK
AXLES: 4
BLOCKS: 16 LEAD
DRIVER: 206, lb
TIRE PRESS.: SELF-INFLATED
AVG. WEIGHT: 80890 lb

	AXLES' WEIGHT, lb				TOTAL	
RUN:	1	2	3	4	WEIGHT	ERROR
1	19780	18980	20660	21060	80480	-0.0051
2	19960	18980	20820	20260	80020	-0.0108
3	20060	19340	21480	19940	80820	-0.0009
4	19960	18940	21460	19920	80280	-0.0075
5	19900	18800	21300	20540	80540	-0.0043
6	19860	18760	21580	20680	80880	-0.0001
7	19820	18720	21360	20720	80620	-0.0033
8	19840	18760	20720	20760	80080	-0.0100
9	19960	18800	21180	20520	80460	-0.0053
10	19880	18720	21240	20520	80360	-0.0066
11	19820	18840	21000	20440	80100	-0.0098
12	19840	18640	21200	20540	80220	-0.0083
13	19860	18660	21480	20560	80560	-0.0041
14	19820	18580	21080	20400	79880	-0.0125
15	19740	18660	21240	20420	80060	-0.0103
16	19740	18540	21200	20560	80040	-0.0105
17	19920	18740	21360	20620	80640	-0.0031
18	19820	18740	21260	20700	80520	-0.0046
19	19700	18540	21040	20380	79660	-0.0152
20	19700	18780	21340	20600	80420	-0.0058
21	19660	18520	21300	20420	79900	-0.0122
22	19740	18740	21240	20420	80140	-0.0093
23	19880	18780	21100	20660	80420	-0.0058
24	19720	18340	21340	20320	79720	-0.0145
25	19600	18640	21200	20420	79860	-0.0127
26	19840	18800	21100	20540	80280	-0.0075
27	19780	18800	21220	20520	80320	-0.0070
28	19800	18700	21220	20500	80220	-0.0083
29	19760	18640	21320	20580	80300	-0.0073
30	19740	18560	21380	20540	80220	-0.0083
Max.	20060	19340	21580	21060	80880	
Min.	19600	18340	20660	19920	79660	

TOTAL	2408020	-0.2309
MEAN	80267.333	-0.0077
STANDARD	303.47338	0.0038
VARIANCE	92096.092	0.0000
COVARIANCE	0.378	-48.7377
% ERROR	0.770	

P.A.T. SCALE DATA: GMC/ARMY TRUCK (Half-load)

DATE: 06/25/92	VEHICLE: GMC/ARMY TRUCK
TIME: 07:30 AM	AXLES: 4
TEMP (F): 87	BLOCKS: 8 LEAD
CONDITION: SUNNY & HUMID	DRIVER: 210, lb
	TIRE PRESS.: SELF-INFLATED
EAST WGHT: 64720 lb	AVG. WEIGHT: 64700 lb
WEST WGHT: 64680 lb	

	AXLES' WEIGHT, lb				TOTAL	
RUN:	1	2	3	4	WEIGHT	ERROR
1	18200	16180	15880	14380	64640	-0.0009
2	18160	16220	15800	14380	64560	-0.0022
3	18120	16200	15780	14340	64440	-0.0040
4	18060	16180	15760	14360	64360	-0.0053
5	18240	16240	15840	14260	64580	-0.0019
6	18120	16160	15820	14280	64380	-0.0049
7	18100	16220	15780	14320	64420	-0.0043
8	18080	16120	15780	14340	64320	-0.0059
9	18160	16220	15860	14260	64500	-0.0031
10	18120	16200	15880	14340	64540	-0.0025
11	18160	16220	15740	14280	64400	-0.0046
12	18180	16140	15840	14360	64520	-0.0028
13	18080	16140	15840	14320	64380	-0.0049
14	18100	16180	15860	14380	64520	-0.0028
15	18140	16120	15780	14320	64360	-0.0053
16	18140	16160	15820	14320	64440	-0.0040
17	18160	16200	15840	14380	64580	-0.0019
18	18100	16120	15680	14300	64200	-0.0077
19	18140	16160	15800	14400	64500	-0.0031
20	18140	16120	15720	14420	64400	-0.0046
21	18160	16160	15840	14340	64500	-0.0031
22	18160	16120	15780	14280	64340	-0.0056
23	18080	16200	15600	14340	64220	-0.0074
24	18120	16140	15680	14320	64260	-0.0068
25	18120	16100	15760	14320	64300	-0.0062
26	18120	16120	15720	14280	64240	-0.0071
27	18140	16100	15780	14360	64380	-0.0049
28	18220	16140	15720	14340	64420	-0.0043
29	18180	16080	15820	14340	64420	-0.0043
30	18140	16120	15740	14320	64320	-0.0059
Max.	18240	16240	15880	14420	64640	
Min.	18060	16080	15600	14260	64200	

TOTAL	1932440	-0.1323
MEAN	64414.667	-0.0044
STANDARD	113.37254	0.0018
VARIANCE	12853.333	0.0000
COVARIANCE	0.176	-39.7334
% ERROR	0.441	

TEST #1

GMC truck load

1. Ho: The sample mean is equal to the population mean

2. H1: The sample mean is not equal to the population mean

3. alpha = 0.05
4. Critical Region: -Z(alpha/2) = -1.96,
   Z(alpha/2) = 1.96
5. Number of observations (runs): n = 30
6. Computations:
   z =(Sample mean - Population mean)/(standard deviation/sqrt(n)) = -11.23821

7. Conclusion: Reject Ho at 0.05 level of significance. There is a significant difference between the sample and population mean

GMC truck half load

1. Ho: The sample mean is equal to the population mean

2. H1: The sample mean is not equal to the population mean

3. alpha = 0.05
4. Critical Region: - Z(alpha/2) = -1.96,
   Z(alpha/2) = 1.96
5. Number of observations (runs): n = 30
6. Computations:
   z =(Sample mean - Population mean)/(standard deviation/sqrt(n)) = -13.78495

7. Conclusion: Reject Ho at 0.05 level of significance. There is a significant difference between the sample and population mean

TEST #2: Cochran's test

1. Ho: The variances of the load and unload samples are equal
2. H1: The variances of the load and unload samples are not equal

3. alpha = 0.05
4. Critical Region: G = 0.686065

17	0.7341
30	x
37	0.6602
x =	0.686065

5. Computations:

S load^2 =	92096.092
S unload^2 =	12853.333
S total =	104949.43
g =	0.1224717 > G then,

6. Conclusion: Reject Ho at 0.05 level of significance. There is a significant difference between the load and unload samples' variance

TEST #3: ANOVA

1. Ho: The load and the unload samples' mean are equal

2. H1: The load and the unload samples' mean are not equal

3. alpha = 0.05
4. Degrees of freedom
   nu 1 = # samples - 1 = 1
   nu 2 = # samples(sample size - 1) = 58

5. Critical region: F > 4.008

40	4.08
58	x
60	4
x =	4.008

6. Computations:

Source of variation	Sum of Squares	Degree of Freedom	Mean Square	Computed f
Aggregates	3.77E+09	1	3769605606.7	71836.6> F then,
Error	3043533.3	58	52474.7	
Total	3.773E+09	59		

7. Conclusion: Reject Ho and conclude that the samples do not have the same mean

P.A.T. SCALE DATA: GMC/ARMY TRUCK (Load)

SPECIAL-TEST:LEVELS ONLY UNDER AXLES NEXT TO SCALES

DATE:06/23/92
TIME:03:32 PM
TEMP (F):118
CONDITION:EXTREME HOT

VEHICLE: GMC/ARMY TRUCK
AXLES: 4
BLOCKS: 16 LEAD
DRIVER: 206, lb
TIRE PRESS.: SELF INFLATED

EAST WGHT:80920 lb
WEST WGHT:80860 lb

AVG. WEIGHT:80890 lb

	AXLES' WEIGHT, lb				TOTAL	
RUN:	1	2	3	4	WEIGHT	ERROR
1	19560	18560	22300	20040	80460	-0.0053
2	19540	18660	21820	20120	80140	-0.0093
3	19540	18720	21440	19940	79640	-0.0155
4	19480	18420	21640	19880	79420	-0.0182
5	19440	18680	21680	20100	79900	-0.0122
6	19520	18620	21440	19840	79420	-0.0182
7	19420	18480	21820	20080	79800	-0.0135
8	19520	18740	21780	20020	80060	-0.0103
9	19440	18200	21840	19880	79360	-0.0189
10	19500	18540	21860	19980	79880	-0.0125
11	19640	18740	21540	20060	79980	-0.0112
12	19380	18660	21740	19980	79760	-0.0140
13	19460	18520	21820	20000	79800	-0.0135
14	19400	18420	21760	19960	79540	-0.0167
15	19520	18500	21260	20020	79300	-0.0197
Max.	19640	18740	22300	20120	80460	
Min.	19380	18200	21260	19840	79300	

TOTAL	1196460	-0.2088
MEAN	79764	-0.0139
STANDARD	324.62726	0.0040
VARIANCE	105382.86	0.0000
COVARIANCE	0.407	-28.8301
% ERROR	1.392	

P.A.T. SCALE DATA: GMC/ARMY TRUCK (Half-load)

SPECIAL-TEST:LEVELS ONLY UNDER AXLES NEXT TO SCALES

DATE:06/24/92
TIME:04:35 PM
TEMP (F):111
CONDITION:SUNNY & HOT

EAST WGHT:64720 lb
WEST WGHT:64680 lb

VEHICLE: GMC/ARMY TRUCK
AXLES: 4
BLOCKS: 8 LEAD
DRIVER: 210, lb
TIRE PRESS.: SELF INFLATED
AVG. WEIGHT:64700 lb

	AXLES' WEIGHT, lb				TOTAL	
RUN:	1	2	3	4	WEIGHT	ERROR
1	17900	16040	15960	13940	63840	-0.0133
2	17700	16300	15900	13980	63880	-0.0127
3	17800	16180	16040	13980	64000	-0.0108
4	17740	16200	15960	14000	63900	-0.0124
5	17640	16180	15880	13860	63560	-0.0176
6	17740	16200	15980	13860	63780	-0.0142
7	17560	16200	16140	13960	63860	-0.0130
8	17820	16200	16040	13980	64040	-0.0102
9	17820	16040	16040	13980	63880	-0.0127
10	17860	16220	16020	13980	64080	-0.0096
11	17820	16260	16000	14020	64100	-0.0093
12	17840	16120	15980	13900	63840	-0.0133
13	17680	16320	16000	13980	63980	-0.0111
14	17880	16240	15900	13960	63980	-0.0111
15	17820	16080	16040	14000	63940	-0.0117
Max.	17900	16320	16140	14020	64100	
Min.	17560	16040	15880	13860	63560	
				TOTAL	958660	-0.1830
				MEAN	63910.667	-0.0122
				STANDARD	134.77318	0.0021
				VARIANCE	18163.81	0.0000
				COVARIANCE	0.211	-17.0743
				% ERROR	1.220	

TEST #1

GMC truck load

1. Ho: The sample mean is equal to the population mean

2. H1: The sample mean is not equal to the population mean

3. alpha = 0.05
4. Critical Region: - Z(alpha/2) = -1.96,
   Z(alpha/2) = 1.96
5. Number of observations (runs): n = 15
6. Computations:
   z =(Sample mean - Population mean)/(standard deviation/sqrt(n)) = -13.4338

7. Conclusion: Reject Ho at 0.05 level of significance. There is a significant difference between the sample and population mean

GMC truck half load

1. Ho: The sample mean is equal to the population mean

2. H1: The sample mean is not equal to the population mean

3. alpha = 0.05
4. Critical Region: - Z(alpha/2) = -1.96,
   Z(alpha/2) = 1.96
5. Number of observations (runs): n = 15
6. Computations:
   z =(Sample mean - Population mean)/(standard deviation/sqrt(n)) = -22.68311

7. Conclusion: Reject Ho at 0.05 level of significance. There is a significant difference between the sample and population mean

TEST #2: Cochran's test

1. Ho: The variances of the load and unload samples are equal
2. H1: The variances of the load and unload samples are not equal

3. alpha = 0.05
4. Critical Region: G = 0.7521

11	0.788
15	x
17	0.7341
x =	0.7520667

5. Computations:

S load^2 =	105382.86
S unload^2 =	18163.81
S total =	123546.67
g =	0.8529802 > G then,

6. Conclusion: Reject Ho at 0.05 level of significance. There is a significant difference between the load and unload samples' variance.

TEST #3: ANOVA

1. Ho: The load and the unload samples' mean are equal

2. H1: The load and the unload samples' mean are not equal

3. alpha = 0.05
4. Degrees of freedom
   nu 1 = # samples - 1 = 1
   nu 2 = # samples(sample size - 1) = 28

5. Critical region: F > 4.20

6. Computations:

Source of variation	Sum of Squares	Degree of Freedom	Mean Square	Computed f
Aggregates	94248067	1	942480666.7	0.3368 < F then,
Error	7.835E+10	28	2798330258.1	
Total	7.93E+10	29		

7. Conclusion: Accept Ho and conclude that the samples do have the same mean

P.A.T. SCALE DATA: 6X6 ARMY TRUCK (Load)

DATE:06/23/92
TIME:10:45 AM
TEMP (F):100
CONDITION:HEAT

VEHICLE: 6X6 ARMY TRUCK
AXLES: 3
BLOCKS: 8 LEAD
DRIVER: 190, lb
TIRE PRESS.: 85 PSI
AVG. WEIGHT:35060 lb

EAST WGHT:35060 lb
WEST WGHT:35060 lb

	AXLES' WEIGHT, lb			TOTAL	
RUN:	1	2	3	WEIGHT	ERROR
1	8420	13268	13460	35148	0.0025
2	8180	13320	13860	35360	0.0086
3	8420	13040	13860	35320	0.0074
4	8360	13240	13560	35160	0.0029
5	8180	13320	13400	34900	-0.0046
6	8380	13420	13580	35380	0.0091
7	8440	13360	13640	35440	0.0108
8	8000	13400	13600	35000	-0.0017
9	8420	13600	13600	35620	0.0160
10	8480	13660	13580	35720	0.0188
11	8460	13520	13500	35480	0.0120
12	8460	13280	13520	35260	0.0057
13	8380	13320	13520	35220	0.0046
14	8360	13400	13600	35360	0.0086
15	8460	13580	13420	35460	0.0114
16	8440	13440	13640	35520	0.0131
17	8340	13640	13520	35500	0.0125
18	8400	13160	13540	35100	0.0011
19	8420	13400	13440	35260	0.0057
20	8400	13300	13480	35180	0.0034
21	8320	13360	13620	35300	0.0068
22	8380	13400	13440	35220	0.0046
23	8320	13640	13520	35480	0.0120
24	8460	13440	13680	35580	0.0148
25	8400	13220	13540	35160	0.0029
26	8340	13380	13780	35500	0.0125
27	8220	13240	13500	34960	-0.0029
28	8420	13360	13580	35360	0.0086
29	8380	13240	13500	35120	0.0017
30	8380	13260	13540	35180	0.0034
Max.	8480	13660	13860	35720	
Min.	8000	13040	13400	34900	
			TOTAL	1059248	0.2124
			MEAN	35308.267	0.0071
			STANDARD	199.6768	0.0057
			VARIANCE	39870.823	0.0000
			COVARIANCE	0.566	80.4284
			% ERROR	0.708	

P.A.T. SCALE DATA: 6X6 ARMY TRUCK (Half-load)

DATE: 06/24/92
TIME: 03:30 PM
TEMP (F): 121
CONDITION: EXTREME HEAT
EAST WGHT: 27160 lb
WEST WGHT: 27140 lb

VEHICLE: 6X6 ARMY TRUCK
AXLES: 3
BLOCKS: 4 LEAD
DRIVER: 190, lb
TIRE PRESS.: 89.5 PSI
AVG. WEIGHT: 27150 lb

RUN:	AXLES' WEIGHT, lb 1	2	3	TOTAL WEIGHT	ERROR
1	8180	9440	9440	27060	-0.0033
2	8080	9340	9480	26900	-0.0092
3	8200	9300	9320	26820	-0.0122
4	8240	9280	9420	26940	-0.0077
5	8260	9140	9540	26940	-0.0077
6	8440	9140	9360	26940	-0.0077
7	8260	9320	9440	27020	-0.0048
8	8360	9400	9400	27160	0.0004
9	8440	9320	9440	27200	0.0018
10	8360	9260	9480	27100	-0.0018
11	8360	9280	9460	27100	-0.0018
12	8320	9400	9600	27320	0.0063
13	8400	9360	9540	27300	0.0055
14	8360	9380	9380	27120	-0.0011
15	8480	9280	9420	27180	0.0011
16	8460	9200	9500	27160	0.0004
17	8360	9220	9560	27140	-0.0004
18	8220	9360	9420	27000	-0.0055
19	8400	9280	9540	27220	0.0026
20	8380	9280	9560	27220	0.0026
21	8360	9320	9480	27160	0.0004
22	8400	9360	9500	27260	0.0041
23	8340	9380	9500	27220	0.0026
24	8380	9400	9460	27240	0.0033
25	8380	9380	9420	27180	0.0011
26	8360	9360	9480	27200	0.0018
27	8360	9400	9520	27280	0.0048
28	8380	9220	9560	27160	0.0004
29	8420	9340	9660	27420	0.0099
30	8520	9360	9660	27540	0.0144
Max.	8520	9440	9660	27540	
Min.	8080	9140	9320	26820	

TOTAL	814500	-0.0000
MEAN	27150	-0.0000
STANDARD	154.54048	0.0057
VARIANCE	23882.759	0.0000
COVARIANCE	0.569	-7.50E+18
% ERROR	0	

TEST #1

6 X 6 army truck load

1. Ho: The sample mean is equal to the population mean

2. H1: The sample mean is not equal to the population mean

3. alpha = 0.05
4. Critical Region:- Z(alpha/2) = -1.96,
   Z(alpha/2) = 1.96
5. Number of observations (runs): n = 30
6. Computations:
   z =(Sample mean - Population mean)/(standard deviation/sqrt(n)) = 6.81006788

7. Conclusion: Reject Ho at 0.05 level of significance. There is a significant difference between the sample and population mean

6 X 6 army truck half load

1. Ho: The sample mean is equal to the population mean

2. H1: The sample mean is not equal to the population mean

3. alpha = 0.05
4. Critical Region:- Z(alpha/2) = -1.96,
   Z(alpha/2) = 1.96
5. Number of observations (runs): n = 30
6. Computations:
   z =(Sample mean - Population mean)/(standard deviation/sqrt(n))

7. Conclusion: Accept Ho at 0.05 level of significance. There are not significant differences between the sample and population mean

TEST #2: Cochran's test

1.Ho: The variances of the load and unload samples are equal
2. H1: The variances of the load and unload samples are not equal

3. alpha = 0.05
4. Critical Region: G = 0.686065

17	0.7341
30	G
37	0.6602
G=	0.686065

5. Computations:

S load^2 =	39870.823
S unload^2 =	23882.7586
S total =	63753.5816
g =	0.62538954 < G then,

6. Conclusion: Accept Ho at 0.05 level of significance. There are not significant differences between the load and unload samples' variance

TEST #3: ANOVA

1. Ho: The load and the unload samples' mean are equal

2. H1: The load and the unload samples' mean are not equal

3. alpha = 0.05
4. Degrees of freedom
   nu 1 = # samples - 1 = 1
   nu 2 = # samples(sample size - 1) = 58

5. Critical region: F > 4.008

40	4.08
58	x
60	4
x =	4.008

6. Computations:

Source of variation	Sum of Squares	Degree of Freedom	Mean Square	Computed f
Aggregates	998359725	1	998359725.1	31319.33>F then,
Error	1848853.87	58	31876.8	
Total	100020858	59		

7. Conclusion: Reject Ho and conclude that the samples do not have the same mean

P.A.T. SCALE DATA: JEEP HONCHO (Load)

DATE:06/23/92
TIME:09:46 AM
TEMP (F):94
CONDITION:SUNNY & HUMID

VEHICLE: JEEP HONCHO
AXLES: 2
BLOCKS: 1 STEEL
DRIVER: 175, lb
TIRE PRES.: 48 PSI

EAST WGT:5160 lb
WEST WGT:5160 lb
AVG. WGT:5160 lb

RUN:	AXLES' WEIGHT, lb 1	2	TOTAL WEIGHT	ERROR
1	2400	2800	5200	0.0078
2	2420	2780	5200	0.0078
3	2400	2800	5200	0.0078
4	2380	2800	5180	0.0039
5	2400	2800	5200	0.0078
6	2400	2800	5200	0.0078
7	2420	2800	5220	0.0116
8	2420	2800	5220	0.0116
9	2420	2800	5220	0.0116
10	2400	2800	5200	0.0078
11	2400	2800	5200	0.0078
13	2400	2780	5180	0.0039
14	2400	2800	5200	0.0078
15	2420	2820	5240	0.0155
16	2420	2820	5240	0.0155
17	2420	2820	5240	0.0155
18	2400	2820	5220	0.0116
19	2420	2820	5240	0.0155
20	2420	2820	5240	0.0155
21	2400	2840	5240	0.0155
22	2440	2800	5240	0.0155
23	2380	2800	5180	0.0039
24	2380	2800	5180	0.0039
25	2380	2780	5160	0.0000
26	2400	2760	5160	0.0000
27	2380	2780	5160	0.0000
28	2400	2780	5180	0.0039
29	2400	2780	5180	0.0039
30	2380	2780	5160	0.0000
Max.	2440	2840	5240	
Min.	2380	2760	5160	

TOTAL	156080	0.2481
MEAN	5202.667	0.0083
STANDARD	27.156	0.0053
VARIANCE	737.471	0.0000
COVARIANCE	0.522	63.6479
% ERROR	0.827	

P.A.T. SCALE DATA: JEEP HONCHO (Half-load)

DATE:06/24/92
TIME:03:05 PM
TEMP (F):112
CONDITION:EXTREME HEAT

VEHICLE: JEEP HONCHO
AXLES: 2
BLOCKS: EMPTY
DRIVER: 175, lb
TIRE PRESS.: 49.5 PSI
AVG. WEIGHT: 4170 lb

EAST WGT:4160 lb
WEST WGT:4180 lb

AXLES' WEIGHT, lb RUN:	1	2	TOTAL WEIGHT	ERROR
1	2400	1760	4160	-0.0024
2	2380	1780	4160	-0.0024
3	2380	1780	4160	-0.0024
4	2400	1780	4180	0.0024
5	2380	1780	4160	-0.0024
6	2380	1780	4160	-0.0024
7	2380	1760	4140	-0.0072
8	2400	1780	4180	0.0024
9	2380	1780	4160	-0.0024
10	2380	1780	4160	-0.0024
11	2400	1780	4180	0.0024
12	2400	1780	4180	0.0024
13	2400	1780	4180	0.0024
14	2400	1780	4180	0.0024
15	2400	1800	4200	0.0072
16	2400	1780	4180	0.0024
17	2400	1780	4180	0.0024
18	2400	1780	4180	0.0024
19	2420	1800	4220	0.0120
20	2400	1780	4180	0.0024
21	2380	1780	4160	-0.0024
22	2380	1780	4160	-0.0024
23	2400	1760	4160	-0.0024
24	2380	1760	4140	-0.0072
25	2380	1780	4160	-0.0024
26	2400	1780	4180	0.0024
27	2420	1780	4200	0.0072
28	2400	1780	4180	0.0024
29	2400	1780	4180	0.0024
30	2380	1780	4160	-0.0024
Max.	2420	1800	4220	
Min.	2380	1760	4140	

TOTAL	125160	0.0144
MEAN	4172	0.0005
STANDARD	17.100	0.0041
VARIANCE	292.414	0.0000
COVARIANCE	0.410	855.0055
% ERROR	0.048	

TEST #1

Jeep with load

1. Ho: The sample mean is equal to the population mean

2. H1: The sample mean is not equal to the population mean

3. alpha = 0.05
4. Critical Region: - Z(alpha/2) = -1.96,
   Z(alpha/2) = 1.96
5. Number of observations (runs): n = 30
6. Computations:
   z =(Sample mean - Population mean)/(standard deviation/sqrt(n)) = 8.60551351

7. Conclusion: Reject Ho at 0.05 level of significance. There is a significant difference between the sample and population mean

Jeep empty

1. Ho: The sample mean is equal to the population mean

2. H1: The sample mean is not equal to the population mean

3. alpha = 0.05
4. Critical Region: - Z(alpha/2) = -1.96,
   Z(alpha/2) = 1.96
5. Number of observations (runs): n = 30
6. Computations:
   z =(Sample mean - Population mean)/(standard deviation/sqrt(n)) = 0.64060702

7. Conclusion: Accept Ho at 0.05 level of significance. There are not significant differences between the sample and population mean

TEST #2: Cochran's test

1. Ho: The variances of the load and unload samples are equal
2. H1: The variances of the load and unload samples are not equal

3. alpha = 0.05
4. Critical Region: G = 0.686065

17	0.7341
30	x
37	0.6602
x =	54.8852

5. Computations:

S load^2 =	737.471264
S unload^2 =	292.413793
S total =	1029.88506
g =	0.71607143 > G then,

6. Conclusion: Reject Ho at 0.05 level of significance. There is a significant differences between the load and unload samples' variance

TEST #3: ANOVA

1. Ho: The load and the unload samples' mean are equal

2. H1: The load and the unload samples' mean are not equal

3. alpha = 0.05
4. Degrees of freedom
   nu 1 = # samples - 1 = 1
   nu 2 = # samples(sample size - 1) = 58

5. Critical region: F > 4.008

40	4.08
58	x
60	4
x =	4.008

6. Computations:

Source of variation	Sum of Squares	Degree of Freedom	Mean Square	Computed f
Aggregates	15934106.7	1	15934106.7	30943.5 > F then,
Error	29866.7	58	514.9	
Total	15963973.3	59		

7. Conclusion: Reject Ho and conclude that the samples do not have the same mean

P.A.T. SCALE DATA: 3S2/BLUE TRACTOR (Load)

DATE: 06/24/92
TIME: 07:37 AM
TEMP (F): 99
CONDITION: SUNNY & HUMID

EAST WGHT: 69320 lb
WEST WGHT: 69200 lb

VEHICLE: 3S2/BLUE TRACTOR
AXLES: 5
BLOCKS: 16 LEAD
DRIVER: 215, lb
TIRE PRESS.: 85 PSI
AVG. WEIGHT: 69260 lb

	AXLES' WEIGHT, lb					TOTAL	
RUN:	1	2	3	4	5	WEIGHT	ERROR
1	9320	13920	13480	16160	16480	69360	0.0014
2	9760	13400	13500	16260	16040	68960	-0.0043
3	9580	14520	13880	16240	16340	70560	0.0188
4	9920	13560	13980	16120	16300	69880	0.0090
5	9200	14020	13420	16200	16220	69060	-0.0029
6	9620	13660	13740	16280	16320	69620	0.0052
7	9740	14580	13720	16260	16240	70540	0.0185
8	9780	14080	13520	16120	16240	69740	0.0069
9	9760	13700	13500	16160	16360	69480	0.0032
10	9760	13980	13700	16260	16280	69980	0.0104
11	9720	13960	13660	16280	16180	69800	0.0078
12	9460	14000	13840	16260	16280	69840	0.0084
13	9540	13820	13760	16140	16380	69640	0.0055
14	9840	13680	13760	16120	16280	69680	0.0061
15	9640	13860	13760	16220	16200	69680	0.0061
16	9520	13980	13840	16180	16240	69760	0.0072
17	9640	13940	13460	16160	16200	69400	0.0020
18	9520	14020	13660	16220	16340	69760	0.0072
19	9800	13840	13600	16180	16360	69780	0.0075
20	9440	14360	13640	15940	16200	69580	0.0046
21	9720	13740	13760	15980	15980	69180	-0.0012
22	9720	14420	13780	15920	15920	69760	0.0072
23	9720	13300	13940	16180	16240	69380	0.0017
24	9780	13880	13580	16280	16180	69700	0.0064
25	9640	13720	13800	16180	16280	69620	0.0052
26	9740	13660	13960	16120	16320	69800	0.0078
27	9820	13820	13900	16180	16160	69880	0.0090
28	9580	13640	13820	16020	16280	69340	0.0012
29	9600	14160	13640	16280	16380	70060	0.0116
30	9620	13920	13820	16380	16180	69920	0.0095
Max.	9920	14580	13980	16380	16480	70560	
Min.	9200	13300	13420	15920	15920	68960	

TOTAL	2090740	0.1868
MEAN	69691.333	0.0062
STANDARD	350.75026	0.0051
VARIANCE	123025.75	0.0000
COVARIANCE	0.503	81.3177
% ERROR	0.623	

P.A.T. SCALE DATA: 3S2/BLUE TRACTOR (Half-load)

DATE:06/25/92
TIME:08:48 AM
TEMP (F):100
CONDITION:SUNNY & HUMID

EAST WGHT:52860 lb
WEST WGHT:52860 lb

VEHICLE:3S2/BLUE TRACTOR
AXLES: 5
BLOCKS: 8 LEAD
DRIVER: 210, lb
TIRE PRESS.: 90 PSI
AVG. WEIGHT:52860 lb

RUN:	AXLES' WEIGHT, lb 1	2	3	4	5	TOTAL WEIGHT	ERROR
1	9800	10760	11180	10580	11000	53320	0.0087
2	9780	10740	11100	10600	10840	53060	0.0038
3	9700	10920	10900	10820	10800	53140	0.0053
4	9580	10800	11020	10800	10800	53000	0.0026
5	9760	10680	10940	10780	10820	52980	0.0023
6	9760	10880	11000	10760	10720	53120	0.0049
7	9860	10800	10740	10760	10780	52940	0.0015
8	9560	10880	11280	10640	10980	53340	0.0091
9	9560	11060	10740	10680	10920	52960	0.0019
10	9800	10560	11300	10760	10940	53360	0.0095
11	9640	10820	10720	10700	10920	52800	-0.0011
12	9560	10980	10880	10740	10860	53020	0.0030
13	9580	10900	10720	10780	10880	52860	0.0000
14	9640	10980	10860	10820	10780	53080	0.0042
15	9760	11020	11040	10760	10880	53460	0.0114
16	9660	10880	10780	10660	10840	52820	-0.0008
17	9580	10580	10820	10720	10840	52540	-0.0061
18	9620	11080	10820	10660	10780	52960	0.0019
19	9720	11100	11060	10700	11080	53660	0.0151
20	9860	10840	10820	10780	10920	53220	0.0068
21	9780	10800	10980	11060	10880	53500	0.0121
22	9880	10840	10940	10760	10860	53280	0.0079
23	9900	10760	10900	10800	10780	53140	0.0053
24	9820	10960	10820	10780	10920	53300	0.0083
25	9820	10800	10840	10720	10980	53160	0.0057
26	9800	10900	10800	10880	10880	53260	0.0076
27	9640	10920	10900	10880	10860	53200	0.0064
28	9820	10900	10800	10680	10880	53080	0.0042
29	9840	11040	10620	10660	11060	53220	0.0068
30	9800	11320	10660	10680	10800	53260	0.0076
Max.	9900	11320	11300	11060	11080	53660	
Min.	9560	10560	10620	10580	10720	52540	

TOTAL	1594040	0.1559
MEAN	53134.667	0.0052
STANDARD	231.03565	0.0044
VARIANCE	53377.471	0.0000
COVARIANCE	0.435	84.1149
% ERROR	0.520	

TEST #1

3S2 truck load

1. Ho: The sample mean is equal to the population mean

2. H1: The sample mean is not equal to the population mean

3. alpha = 0.05
4. Critical Region: - Z(alpha/2) = -1.96,
   Z(alpha/2) = 1.96
5. Number of observations (runs): n = 30

6. Computations:
   z =(Sample mean - Population mean)/(standard deviation/sqrt(n)) = 6.73559

7. Conclusion: Reject Ho at 0.05 level of significance. There is a significant difference between the sample and population mean

3S2 truck half load

1. Ho: The sample mean is equal to the population mean

2. H1: The sample mean is not equal to the population mean

3. alpha = 0.05
4. Critical Region: - Z(alpha/2) = -1.96,
   Z(alpha/2) = 1.96
5. Number of observations (runs): n = 30

6. Computations:
   z =(Sample mean - Population mean)/(standard deviation/sqrt(n)) = 6.5115981

7. Conclusion: Reject Ho at 0.05 level of significance. There is a significant difference between the sample and population variance

TEST #2: Cochran's test

1. Ho: The variances of the load and unload samples are equal

2. H1: The variances of the load and unload samples are not equal
3. alpha = 0.05
4. Critical Region: G = 0.686065

17	0.7341
30	x
37	0.6602
x =	43.90816

5. Computations:

S load^2 =	123025.75
S unload^2 =	53377.471
S total =	176403.22
g =	0.6974121 > G then,

6. Conclusion: Reject Ho at 0.05 level of significance. There is a significant difference between the load and unload samples' variance

TEST #3: ANOVA

1. Ho: The load and the unload samples' mean are equal

2. H1: The load and the unload samples' mean are not equal

3. alpha = 0.05
4. Degrees of freedom
   nu 1 = # samples - 1 = 1
   nu 2 = # samples(sample size - 1) = 58

5. Critical region: F > 4.008

40	4.08
58	x
60	4
x =	4.008

6. Computations:

Source of variation	Sum of Squares	Degree of Freedom	Mean Square	Computed f
Aggregates	4.11E+09	1	4111848166.7	46618.7> F then,
Error	5115693.3	58	88201.609195	
Total	4.117E+09	59		

7. Conclusion: Reject Ho and conclude that the samples do not have the same mean

APPENDIX D

DIFFERENCE BETWEEN THE MEASURED AND TRUE WEIGHT

Equation D.1 shows how the difference between the true and the measured weight was calculated. These differences can be used to evaluate the PAT accuracy. For each vehicle measure, the mean, standard deviation, and variance were calculated. The number of runs was calculated using the standard deviation of the difference and the percent of accuracy desired.

$$Difference = \frac{Measure\ weight - True\ weight}{True\ weight} \qquad (D.1)$$

LOAD	JEEP	AT6X6	GMC	GMCS	T3S2
	0.0078	0.0025	-0.0051	-0.0053	0.0014
	0.0078	0.0086	-0.0108	-0.0093	- 0.0043
	0.0078	0.0074	-0.0009	-0.0155	0.0188
	0.0039	0.0029	-0.0075	-0.0182	0.0090
	0.0078	-0.0046	-0.0043	-0.0122	- 0.0029
	0.0078	0.0091	-0.0001	-0.0182	0.0052
	0.0116	0.0108	-0.0033	-0.0135	0.0185
	0.0116	-0.0017	-0.0100	-0.0103	0.0069
	0.0116	0.0160	-0.0053	-0.0189	0.0032
	0.0078	0.0188	-0.0066	-0.0125	0.0104
	0.0078	0.0120	-0.0098	-0.0112	0.0078
	0.0078	0.0057	-0.0083	-0.0140	0.0084
	0.0039	0.0046	-0.0041	-0.0135	0.0055
	0.0078	0.0086	-0.0125	-0.0167	0.0061
	0.0155	0.0114	-0.0103	-0.0197	0.0061
	0.0155	0.0131	-0.0105		0.0072
	0.0155	0.0125	-0.0031		0.0020
	0.0116	0.0011	-0.0046		0.0072
	0.0155	0.0057	-0.0152		0.0075
	0.0155	0.0034	-0.0058		0.0046
	0.0155	0.0068	-0.0122		- 0.0012
	0.0155	0.0046	-0.0093		0.0072
	0.0039	0.0120	-0.0058		0.0017
	0.0039	0.0148	-0.0145		0.0064
	0.0000	0.0029	-0.0127		0.0052
	0.0000	0.0125	-0.0075		0.0078
	0.0000	-0.0029	-0.0070		0.0090
	0.0039	0.0086	-0.0083		0.0012
	0.0039	0.0017	-0.0073		0.0116
	0.0000	0.0034	-0.0083		0.0095
MEAN	0.0083	0.0071	-0.0077	-0.0139	0.0062
STND	0.0053	0.0057	0.0038	0.0040	0.0051
VAR	0.0000	0.0000	0.0000	0.0000	0.0000

Accuracy			Number of runs		
1	1.0640	1.2461	0.5407	0.6187	0.9852
2	0.2660	0.3115	0.1352	0.1547	0.2463
3	0.1182	0.1385	0.0601	0.0687	0.1095

UNLOAD

	JEEP	AT6X6	GMC	GMCS	3S2
	-0.0024	-0.0033	-0.0009	-0.0133	0.0087
	-0.0024	-0.0092	-0.0022	-0.0127	0.0038
	-0.0024	-0.0122	-0.0040	-0.0108	0.0053
	0.0024	-0.0077	-0.0053	-0.0124	0.0026
	-0.0024	-0.0077	-0.0019	-0.0176	0.0023
	-0.0024	-0.0077	-0.0049	-0.0142	0.0049
	-0.0072	-0.0048	-0.0043	-0.0130	0.0015
	0.0024	0.0004	-0.0059	-0.0102	0.0091
	-0.0024	0.0018	-0.0031	-0.0127	0.0019
	-0.0024	-0.0018	-0.0025	-0.0096	0.0095
	0.0024	-0.0018	-0.0046	-0.0093	- 0.0011
	0.0024	0.0063	-0.0028	-0.0133	0.0030
	0.0024	0.0055	-0.0049	-0.0111	0.0000
	0.0024	-0.0011	-0.0028	-0.0111	0.0042
	0.0072	0.0011	-0.0053	-0.0117	0.0114
	0.0024	0.0004	-0.0040		- 0.0008
	0.0024	-0.0004	-0.0019		- 0.0061
	0.0024	-0.0055	-0.0077		0.0019
	0.0120	0.0026	-0.0031		0.0151
	0.0024	0.0026	-0.0046		0.0068
	-0.0024	0.0004	-0.0031		0.0121
	-0.0024	0.0041	-0.0056		0.0079
	-0.0024	0.0026	-0.0074		0.0053
	-0.0072	0.0033	-0.0068		0.0083
	-0.0024	0.0011	-0.0062		0.0057
	0.0024	0.0018	-0.0071		0.0076
	0.0072	0.0048	-0.0049		0.0064
	0.0024	0.0004	-0.0043		0.0042
	0.0024	0.0099	-0.0043		0.0068
	-0.0024	0.0144	-0.0059		0.0076
MEAN	0.0005	-0.0000	-0.0044	-0.0122	0.0052
STND	0.0041	0.0057	0.0018	0.0021	0.0044
VAR	0.0000	0.0000	0.0000	0.0000	0.0000

Accuracy		Number of runs			
1	0.6460	1.2447	0.1180	0.1667	0.7339
2	0.1615	0.3112	0.0295	0.0417	0.1835
3	0.0718	0.1383	0.0131	0.0185	0.0815

APPENDIX E

NUMBER OF RUNS REQUIRED TO REPLICATE THE WEIGHING CONDITIONS

The number of runs for confidence level of 95 percent was calculated using Equation 2.1. The vehicles weight are expressed in pounds.

ACCURACY OF 1%
Z = 1.96 ERROR 0.01

LOAD

TYPE OF VEHICLE	EAST WEIGHT	WEST WEIGHT	AVERAGE WEIGHT	SAMPLE WEIGHT	STAND. DESV.	N
Jeep	5160	5160	5160	5202.67	27.16	1.06
3S2	69320	69200	69260	69691.33	350.75	0.99
GMC	80920	80860	80890	80267.33	303.47	0.54
GMCS	80920	80860	80890	79764.00	324.63	0.62
AT6X6	35060	35060	35060	35308.27	199.68	1.25

UNLOAD

TYPE OF VEHICLE	EAST WEIGHT	WEST WEIGHT	AVERAGE WEIGHT	SAMPLE WEIGHT	STAND. DESV.	N
Jeep	4180	4160	4170	4172.00	17.10	0.65
3S2	52860	52860	52860	53134.67	231.04	0.73
GMC	64720	64680	64700	64414.67	113.37	0.12
GMCS	64720	64680	64700	63910.67	134.77	0.17
AT6X6	27160	27140	27150	21150.00	154.54	1.24

ACCURACY OF 2%
Z 1.96 ERROR 0.02

LOAD

TYPE OF VEHICLE	EAST WEIGHT	WEST WEIGHT	AVERAGE WEIGHT	SAMPLE WEIGHT	STAND. DESV.	N
Jeep	5160	5160	5160	5202.67	27.16	0.27
3S2	69320	69200	69260	69691.33	350.75	0.25
GMC	80920	80860	80890	80267.33	303.47	0.14
GMCS	80920	80860	80890	79764.00	324.63	0.15
AT6X6	35060	35060	35060	35308.27	199.68	0.31

UNLOAD

TYPE OF VEHICLE	EAST WEIGHT	WEST WEIGHT	AVERAGE WEIGHT	SAMPLE WEIGHT	STAND. DESV.	N
Jeep	4180	4160	4170	4172.00	17.10	0.16
3S2	52860	52860	52860	53134.67	231.04	0.18
GMC	64720	64680	64700	64081.33	1832.02	7.70
GMCS	64720	64680	64700	63910.67	134.77	0.04
AT6X6	27160	27140	27150	21150.00	154.54	0.31

ACCURACY OF 3%

Z = 1.96 ERROR 0.03

LOAD

TYPE OF VEHICLE	EAST WEIGHT	WEST WEIGHT	AVERAGE WEIGHT	SAMPLE WEIGHT	STAND. DESV.	N
Jeep	5160	5160	5160	5202.67	27.16	0.12
3S2	69320	69200	69260	69691.33	350.75	0.11
GMC	80920	80860	80890	80267.33	303.47	0.06
GMCS	80920	80860	80890	79764.00	324.63	0.07
AT6X6	35060	35060	35060	35308.27	199.68	0.14

UNLOAD

TYPE OF VEHICLE	EAST WEIGHT	WEST WEIGHT	AVERAGE WEIGHT	SAMPLE WEIGHT	STAND. DESV.	N
Jeep	4180	4160	4170	4172.00	17.10	0.07
3S2	52860	52860	52860	53134.67	231.04	0.08
GMC	64720	64680	64700	64081.33	1832.02	3.42
GMCS	64720	64680	64700	63910.67	134.77	0.02
AT6X6	27160	27140	27150	21150.00	154.54	0.14

APPENDIX F

PAT CONFIDENCE INTERVALS

The confidence intervals were calculated using Equation 5.1.

ACCURACY OF 1%
Z 1.96 ERROR 0.01

LOAD

	CONFIDENCE INTERVAL				RANGE	
	MEAN		VARIANCE		MEAN	VARIANCE
Jeep	5192.9	5212.4	1124.2	7920.7	19.4	6796.5
3S2	69565.8	69816.8	187549.2	1321387.9	251.0	1133838.8
GMC	80158.7	80375.9	140397.8	989180.4	217.2	848782.6
GMCs	79647.8	79880.2	160653.1	1131890.2	232.3	971237.2
AT6X6	35236.8	35379.7	60781.9	428242.2	142.9	367460.3

UNLOAD

	CONFIDENCE INTERVAL				RANGE	
	MEAN		VARIANCE		MEAN	VARIANCE
Jeep	4165.9	4178.1	445.8	3140.7	12.2	2694.9
3S2	53051.9	53217.3	81372.6	573315.3	165.4	491942.7
GMC	63425.8	64736.9	5116581.4	36049158	1311.2	30932577.0
GMCs	63862.4	63958.9	27690.2	195092.8	96.5	167402.6
AT6X6	21094.7	21205.3	36408.8	256520.3	110.6	220111.5

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